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14 MeV HIGH INTENSITY NEUTRON FACILITY

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AN INJECTOR SYSTEM FOR THE
14 MeV HIGH INTENSITY NEUTRON FACILITY*

J. W. Beal

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Introduction

A proposal¹ for a new 14 MeV high intensity neutron facility has been submitted to AEC-DCTR by Lawrence Livermore Laboratory. One of the key ingredients of this proposed facility is an accelerator capable of producing deuterium ion beams in the 400-500 keV range with a D^+ beam current of up to 150 mA. The proposed accelerator has the added requirement that it operate dc.

The purpose of this facility is to provide an intense source of 14 MeV neutrons. The accelerator is utilized to produce a beam of energetic deuterium ions. These energetic particles are then directed onto a suitable target which will in turn generate high flux densities of 14 MeV neutrons. This neutron flux will be used to study radiation damage, etc. in materials and thus help to generate reliable guidelines for the selection of materials suitable for CTR applications.

The injector power supply is proposed to be a 500 kV Cockcroft-Walton generator capable of handling total beam current loads of up to 250 mA dc. The Cockcroft-Walton generator will be designed so that it

*Work performed under the auspices of the U.S. Atomic Energy Commission.

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can be expanded to a 500 kV, 500 mA, dc capability if desired. The ion source will be a von Ardenne duoplasmatron, and the accelerating column will be designed for a total beam current of up to 200 mA (this implies 140-150 mA of D^+ ion species). This portion of the apparatus is housed inside a Faraday cage to shield the equipment from stray electrostatic and r.f. fields. The beam from the column passes through a series of quadrupoles and bending magnets to be directed to the experimental areas.

This report describes the conceptual layout of the injector system and its necessary components. Suggestions and examples are given with which to meet some of the requirements. This report is not meant to be a detailed design study but is an outline of the design problems that must be solved.

Accelerator Layout and Faraday Cage

A schematic layout of the accelerator is shown in Fig. 1. The Faraday cage is a large light-construction vault which provides a well-defined ground potential plane and a controlled dust free environment for the high voltage equipment. This metal surface is electrically isolated from the remainder of the building and serves also as a shield for radiated fields. The Cockcroft-Walton rectifier and high voltage dome are housed in the Faraday cage together with the high voltage oscillator. For reliable operation it would be desirable to control the temperature and humidity within the Faraday cage. In a high voltage environment, temperature and humidity are typically maintained at $22 \pm 1^\circ\text{C}$ and $45 \pm 5\%$, respectively.

Access to the Faraday cage will be provided by several doorways of various sizes; these doors will of course be interlocked to the high voltage supply. In addition, access to the high voltage dome itself will be provided via a drawbridge or similar walkway. It is expected that most of the maintenance will be on the equipment housed within the high voltage dome itself; therefore ready access to the dome is a necessity. Moreover, it may be desirable to make several of the roof sections of the Faraday cage removable allowing an overhead crane to be used for moving large units of equipment into and out of the Faraday cage and high voltage dome.

Standard floor trenching would be used within the vault for power and water supply lines to the rectifier, oscillator and to the pit below the high voltage dome. Observation of the equipment within the cage during operation would be possible through lead glass windows.

A large (~ 1 meter square) aluminum plate, electrically insulated from the cage wall, could be mounted within the cage at the height of the high voltage dome. This surface can act as a capacitive pickup to observe changes in the potential of the high voltage dome.

A mechanical services room would be adjacent to the Faraday cage housing cooling equipment, LCW equipment, etc. Also, power supplies, circuit breakers, etc. would be housed in an adjacent electrical services room. The main control panel for the high voltage supply and data acquisition system for the accelerator would be located in an adjacent control room.

Accelerator Power Supply

The injector power supply will be a 500 kV, 250 mA cascade Cockcroft-Walton generator. Figure 2 is a schematic of this type of apparatus. Initially, the Cockcroft-Walton generator will have an output of 250 mA; however, the output current can be increased, if warranted, to a full output of 500 mA with the addition of more diode strings. The initial installation will include the expensive, long lead-time items such as transformers, etc.

The cascade rectifier will be driven by a 250 kW, 50 kV, 10 kHz oscillator. If possible, the frequency of the oscillator will be made even higher in order to further reduce the stored energy in the rectifier string. The output voltage of the rectifier is monitored by a precision voltage divider and is regulated by a hard tube modulator controlling the oscillator plate and screen voltages. The output voltage will be regulated to $\pm 0.01\%$. Peak-to-peak ripple will be less than 0.05%. A fast crowbar will be provided to protect the power supply in the event of a sparkdown.

High Voltage Dome

The ion source and its ancillary equipment will operate at potentials of up to 500 kV. This equipment will be housed in an aluminum enclosure (the HV dome) that will sit atop insulating legs inside the Faraday cage, Fig. 3. The HV dome will be a cubical shell several meters along each side with cylindrical edges and spherical corners. The surface finish of the dome must be highly polished to minimize potential stress concentrations.

As an illustrative example consider the case of a 1 MV dome potential and a minimum dome to ground plane separation of 3 m. (The accelerating column side of the dome is closer than this, but the potential is graded by the column itself.) Using a sphere (rad = 600 mm) to plane approximation,³ the maximum voltage gradient is 1.8 kV/mm, well below the air corona limit of 3.1 kV/mm.

The HV dome and leg structure will be designed to support the dome and its equipment and to insulate the equipment from the ground plane. In addition, the support structure must be designed to mechanically isolate the accelerating column from vibrations which may disturb the alignment of the column or put damaging stress on the joints of the column itself. Vibrations originate from the generator which supplies a.c. power to the dome equipment and from personnel working inside the dome.

Typical installations use epoxy-resin bonded fiberglass for the dome legs with "floating" floors in the dome to support the equipment. Fiberglass is chosen as the leg material because of its mechanical strength and electrical insulation properties. This material is also generally impervious to moisture. The "floating" floor design effectively isolates the accelerating column from the vibration sources. The total weight to be supported may be as much as 4000 kg.

Aluminum corona rings will be attached to the support legs at proper intervals between the HV dome and the floor of the Faraday cage. The potential of these rings may be defined, for example, by resistor bleeder chains wound inside the leg supports.

Motor-Generator Assembly

Power to the equipment in the dome will be supplied by a synchronous generator. Generators for such use are typically 400-800 Hz, 208 V and deliver 25 kVA at 3600 rpm. In addition, another, smaller generator will be installed, possibly on the same drive shaft, providing 60 Hz, 115 V, 5 kVA. Mechanical drive for these generators comes from an insulating drive shaft coupled to an induction motor mounted outside the Faraday cage in the equipment pit. This insulating drive shaft spans the high voltage interface between the equipment pit and the HV dome. An induction motor rated at 50 hp at 3600 rpm would be required to provide the necessary power. See Fig. 3.

The insulating drive shaft itself must be carefully designed not to shear under full-load torque and also not to operate near a resonance speed for the shaft assembly. The approach of some installations to solving this problem is to couple a speed-reducer to the drive motor and to couple a speed-increaser to the generator thereby operating the drive shaft at a lower speed. The drive shaft may also have to be resistively graded similarly to the support legs to avoid corona and sparkdown problems.

Dome and Pit Cooling

It is expected that the drive motor, generators and speed reducers (if used) will require oil cooling of bearings and gear trains. An oil pump and water cooled heat exchanger capable of maintaining the oil temperature less than 40°C would be installed in the equipment pit to cool the drive motor and speed reducer.

Cooling within the HV dome is necessary for the speed increaser, generator, ion source and power supplies. If a damping resistor is used to connect the output of the Cockcroft-Walton rectifier to the HV dome, it would probably be oil filled and would require cooling. Such cooling to the HV dome would be provided by running demineralized water to the dome through piping adjacent to the dome support legs. Potential grading of these lines would be achieved by passing them through the aluminum corona rings. Teflon tubing could be used but might be too good an insulator allowing excessive charge build-up and eventual arcdown and tubing puncture. A possible cure would be to use Saran tubing. The heat exchanger, pumps, and on-line water purifier for this cooling system would be located in the mechanical services room.

In the HV dome, the cooling water is run through the ion source and its high current power supplies, through copper cooling plates attached to the speed increaser and/or generator, and through the heat exchanger which cools the damping resistor oil. Additional cooling for the dome interior is provided by circulating air through several large screen covered openings in the roof and walls.

Dome Equipment

Housed within the HV dome will be the ion source and pumping manifold, the damping resistor cooling system, a 50 kV extractor electrode power supply and the power generator and power supplies required to drive these units and also to provide remote monitoring and control of them. Also, there will be two 1500 l/sec ion pumps within the HV dome. Again,

this equipment must be mechanically isolated so as to minimize the transmission of vibrations to the accelerating column.

Fig. 4 shows a block diagram of the major electrical equipment located within the HV dome for a typical installation. Power is provided by the 400 Hz and 60 Hz generators as described above. A sensing circuit provides a remotely monitored interaction of the loss of one or more phases of the generator.

Remote control and monitoring of equipment within the HV dome can be provided across the high voltage interface by possibly fiber-optic light link or lens focussed air light link telemetry. Analogue information would be transmitted as a pulse width modulated system thereby making the accuracy independent of optical transmission losses. If fibre-optic bundles are used, they would have to be routed to ground potential via the resistor-graded dome supporting legs and then to coding-decoding units. A more complete description of the control system is given in a later section of this report.

The ion source power supplies would be 400 Hz versions of the standard ion source test stand supplies. Telemetric coupled metering circuits and motor drives for the input variacs would be added to provide remote parameter adjustment. A motor-driven needle-valve assembly could control the deuterium gas flow rate to the ion source. The source pressure would be monitored by appropriate ion and thermocouple gauges.

Also within the dome would be the 50 kV extractor electrode power supply. A stepping motor would be added for remote adjustment of the voltage as well as added current and voltage monitoring circuits and

status and reset relays. The two ion pumps would be located within the HV dome. Circuits would be added to allow for remote readings of the pump current, for alarm triggering when the pumps are tripped off by overcurrent protects, and for remote resetting of the pump supplies.

Ion Source

A duoplasmatron ion source will be used. If properly constructed, it can provide beams with good optical properties over a wide range of beam currents. Figure 5 shows a cross section of a typical duoplasmatron ion source.

One of the limitations on the operation of this type of ion source is the cathode lifetime. The example shown in Figure 5 utilizes a tungsten wire filament. This type of filament generally has a lifetime of several hundred hours. Another approach has been to make the cathode a barium oxide-strontium oxide electron emitter. Properly designed with heat shields, this type of cathode can produce the required emission with a power consumption of 100 watts at 40 A. Lifetimes of several thousand hours have been reported for this type of cathode. The design of the cathode assembly should allow for easy maintenance.

The intermediate electrode (I.E.) is isolated electrically from the anode and the arc is generally operated as two parallel discharges between the I.E. to anode and filament to anode. The I.E. and source magnet may be cooled by freon or by water (as shown in Fig. 5). Freon is possibly better in that it would be less damaging to the accelerating column in the event of a leak.

The choice of dimensions and materials of the anode and expansion cup depend upon the details of the design. Generally, however, the distance between the I.E. and anode should be small in order to reduce plasma oscillations to a negligible level. If the anode aperture is small compared to the discharge column, then it is expected that the transverse current density will be uniform; therefore the number of extracted ions is just proportional to the aperture area. If the expansion cup is magnetically shielded by a "system" from the discharge side of the anode and the expansion cup is kept short, there will be little beam disturbance or deuteron loss during expansion. This system must be designed so as to not saturate or reach temperatures above the Curie point at operational magnetic field strengths of 1 kG.

The deuterium gas into the source must be reliably controlled. A needle-valve assembly or palladium tube leak would be acceptable. The deuterium gas flow will be approximately 3 cc atm/min (~ 0.04 Torr l/sec). Pressure within the discharge volume of the source will be about 0.5 Torr. This pressure would be monitored by a thermocouple gauge.

Accelerating Column Design

The accelerating column is located between the high voltage dome and the wall of the Faraday cage. This column will be designed for the space charge equivalent of a 200 mA beam of deuterons assuming zero emittance. To compensate for space charge divergence of the beam during acceleration, the Pierce⁵ gradient is generally used; i.e., in mks units

$$V = \left(\frac{9}{4\epsilon_0} \frac{j}{\sqrt{2 \frac{e}{m}}} \right)^{2/3} z^{4/3} \quad (1)$$

where

V = applied voltage

ϵ_0 = dielectric constant of free space

m = mass of the particle

e = charge of the particle

j = beam current density

z = distance from the emitting surface.

For deuterons (D^+ ; $m_0 c^2 = 1877.8$ MeV) and with $j = 70$ mA/cm² ($I = 200$ mA, $r = 0.95$ cm) the result is

$$V = 6.913 \times 10^6 z^{4/3}. \quad (2)$$

Therefore for $V = 400$ kV, Eq. (2) yields the result $z = 11.8$ cm. Also, by taking the first derivative of Eq. (2) the result for the gradient is $dV/dz = 45.2$ kV/cm at the high gradient end of the column. This is a quite high gradient and hence requires careful electrode design and fabrication.

However, space charge effects decrease as the beam energy increases. Therefore in order to reduce the maximum vacuum gradient, a Pierce potential distribution up to (say) 200 keV could be used followed by a uniform gradient for the rest of the column. This approach would give a Pierce

distribution over the first 7.0 cm and a uniform gradient of 38.0 kV/cm thereafter. The choice of such a transition point is somewhat arbitrary; it is a compromise between the deleterious effects on the beam over the non-Pierce section and the maximum electric field.

The number of electrodes in the column is chosen to give the least complicated system that satisfies the requirements. It is known⁶ that the voltage that can be held across two electrodes varies approximately as the square root of the separation; i.e., it is better to hold a given field in a series of gaps rather than a single gap. Therefore, a choice of maximum gradient of 38.0 kV/cm and 75 kV gaps should satisfy the criterion of no breakdown although some conditioning will undoubtedly be required.

The second factor in the choice of the number of electrodes is the ability of the column to withstand micro-discharges. During a micro-discharge between two electrodes, the potential difference collapses and the other gaps in the column have to assume a greater voltage until the transient decays. The distribution of this voltage transient among the other gaps depends upon the inter-electrode capacities and where the discharge occurs. The gaps should be designed to withstand a 15-20% voltage transient.

In accelerating a dc beam, beam current intercepted by the accelerating electrodes is a much more serious problem than in pulsed operations. For pulsed beams, the inter-electrode capacity is sufficient to absorb quite a serious spill. In dc operations the important parameter is the intercepted beam current compared to the normal current drain in the resistive voltage divider chain. This resistor chain sets the potentials on the accelerating electrodes. If the intercepted beam current is significant

compared to the normal current drain in the divider, then the field distribution will be distorted by increasing the potential drop across downstream gaps at the expense of the potential drop in the upstream gaps.

Field distortion is more serious in the early acceleration stages. Therefore, the first accelerating electrode, i.e., the extractor, will be powered from a separate 0-50 kV supply in the dome. This electrode will act as a grid and need only supply the current that it intercepts.

Backstreaming electrons in the column produce unwanted X-rays. These electrons are produced by ionization of the gas in the column by the beam and electrons generated by these processes beyond the column. To eliminate this last source, the last electrode will be held at a voltage negative relative to the beam line to act as a potential barrier to electrons produced beyond the column. The potential for this suppressor electrode comes from a separate power supply operating at about -10 kV.

Figure 6 shows an example of a typical column operating at 750 kV total. This column is designed so as to have a Pierce distribution for the first 200 keV and uniform thereafter. The electron trap is at the last gap. The maximum gradient for this column is 31 kV/cm.

Beam Optics

The ion optics of the accelerating column does not lend itself to a particularly elegant solution. The problem is complicated by the finite emittance of the beam, space charge forces, a mixture of mass components and the initial ion optics determined by the plasma-beam interface. The best approach would be to treat the system numerically.

Consider first space charge defocussing in the non-Pierce section of the column. The first 200 keV of the column would be a Pierce design to accelerate the beam without expansion. However, the beam will expand in the uniform gradient of the next 200 keV of acceleration. The behavior of the beam envelope is determined by using Gauss's theorem to determine the radial acceleration of a peripheral particle; namely

$$\ddot{r} = \frac{I}{2\pi r \epsilon_0} \sqrt{\frac{e}{2mV}} \quad (3)$$

Equation (3) could be integrated numerically to determine the beam envelope.

The dominating influence of the last two gaps of the column is the focussing action of the spatially varying electric field; i.e., in the electron trap. It is possible to treat these last three electrodes as thin lenses with focal lengths given by⁵

$$\frac{1}{f} = \frac{E_2 - E_1}{4V} \quad (4)$$

where eV is the ion energy and E_1 and E_2 are the axial electric fields upstream and downstream from the electrode.

Consider next how the mass distribution affects the beam optics. A typical mass distribution is 75% D^+ , 20% D_2^+ and 5% D_3^+ . To correct for this it is necessary in Eq. (1) that the extracted current, I_{ext} , be replaced by an effective current, I_{eff} , given by

$$I_{\text{eff}} = I_{\text{ext}} \left[f_1 + f_2 \sqrt{2} + f_3 \sqrt{3} \right]. \quad (5)$$

From Eq. (5) it is seen that if the column is designed for 200 mA of D^+ , then it should operate with a total extracted current of 178.7 mA in order to maintain the proper Pierce potential distribution.

The beam diameter increases throughout the column because of its finite emittance. Typical values of normalized emittance, ϵ_1 ($\epsilon_1 = \text{Area}/\pi \beta\gamma$) are ~ 0.3 mrad-cm. The envelope of the drifting beam due to the influence of emittance alone will be determined by

$$r = \left(r_o^2 + \frac{L^2 \epsilon^2}{r_o^2} \right)^{1/2} \quad (6)$$

where

r_o = initial beam radius at a waist

L = drift distance

$\epsilon = \text{Area}/\pi = \epsilon_1/\beta\gamma$.

For the condition of a drifting beam at 400 keV ($\beta\gamma \approx .02$) and $r_o = 1$ cm, the result from Eq. (6) is $r = 1.24$ cm at $L = 50$ cm.

A numerical study of beam optics is therefore in order to determine beam trajectories under the simultaneous influence of all of these effects. Such a theoretical model for the beam envelop in an axially symmetric electromagnetic field does exist given by the relation⁷

$$\begin{aligned} r'' = & \frac{r \dot{V}}{v_z^2} - \frac{r}{2} \frac{n}{v_z^2} \ddot{V} \\ & - \frac{r}{4} \left(\frac{n B_z}{v_z} \right)^2 + \frac{n I}{2 \pi \epsilon_0 v_z^3 \gamma^2 r} + \frac{\epsilon^2}{r^3} \end{aligned} \quad (7)$$

where

$$\eta = e/m = e/m_0 \gamma$$

$$\gamma = (1 - v^2/c^2)^{-1/2}$$

primes denote differentiation with respect to z .

The first two terms on the right of Eq. (7) represent the focussing due to external electric fields. The third term represents focussing due to external solenoidal magnetic fields. The fourth term represents the difference between the defocussing space charge force and the focussing self magnetic force. The last term on the right of Eq. (7) represents the beam expansion due to the finite emittance of the beam. Eq. (7) has been solved via a computer code⁸ and can be used to aid in the design of the accelerating column.

Source and Column Vacuum System

The column and source will be pumped at the dome end by two 1500 ℓ /sec (nominal air) ion pumps. One of these ion pumps could possibly be a diode and the other a triode. This combination would give greater pumping speed for some of the residual gas.

The final design of the vacuum system and pumping manifold will be chosen on the basis of an ion source gas efficiency of $\sim 50\%$; i.e., a gas load of ~ 0.04 torr- ℓ /sec. Ion pumps can accomodate prolonged hydrogen-like consumption provided $p \sim 10^{-6}$ torr; hence a pumping speed of $\sim 10^4$ ℓ /sec is required. At normal operating conditions, the pressure at the pump throats should be $\sim 3 \times 10^{-6}$ torr and near the source $\sim 8 \times 10^{-6}$ torr.

Accelerating Electrodes and Vacuum Vessel

As noted, the accelerating column is located between the high voltage dome and the wall of the Faraday cage. To obtain the transition from an acceptable voltage gradient in air to the high vacuum gradients required in the accelerating region, several design approaches are in use in present-day installations. One method is to design accelerating gaps which are re-entrant in a vacuum vessel which is in turn re-entrant in a SF_6 vessel with air outside. A second approach is to design a single-walled vacuum vessel with re-entrant accelerating gaps directly to air on the outside. Both of these designs are difficult due to their size, being supported only on the ends, and the necessity of having ready access to the ion source at one end of the column.

One of the prime considerations in the choice of the accelerating column fabrication is that the bonding agent for the metal-ceramic seal have a low vapor pressure in order to minimize contamination of the accelerating electrodes and insulators. Carbon tracks on the ceramic would be disastrous. Most installations use accelerating columns glued together either with polyvinyl acetate or epoxy. LLL experience with brazed joints has been successful and should be investigated for this application.

The electrodes will be fabricated out of titanium alloy (for example Ti-7Al-4Mo), chosen mainly because of its excellent voltage holding capacity in vacuum. Individual electrodes will be machined to tight tolerances and also highly polished. The electrodes will be shaped so that nowhere does the beam "see" the ceramic rings. Corona rings will be designed and installed such that the maximum electric field should have a safety factor of at least two over the corona limit.

Again, a typical accelerating column is shown in Figure 6. For this case this vacuum column is surrounded by an SF_6 vessel. This SF_6 column is about 1 meter in diameter, 1.5 meters long, operating at ~ 0.6 psig. The SF_6 vessel is made of lucite bonded with epoxy to aluminum corona rings.

Typically, potential-grading resistor strings are located between the corona rings on the air side; they define a potential difference of ~ 50 kV between adjacent rings. These resistors should be protected from damaging over-voltages by spark-gaps mounted between adjacent corona rings in parallel with the resistors.

Beam Line

The beam line will be designed so as to transport the desired beam current to the target with proper beam optics. In addition, the transport system will be used to analyze and separate the beam into its various mass states.

The exact layout of the transport system will be determined by computer program analysis. The program TRANSPORT⁹ utilizing a matrix formulation of beam optics will be used to make this detailed study of the beam line. Quadrupole lens transport will be used with the lenses arranged in doublets or triplets. It might be better to use a pair of doublets for focussing rather than a triplet due to the reduced ellipticity of the beam and also greater flexibility of operation with four variables. Typical quadrupoles would be ~ 15 cm effective length with an aperture of 10 cm and a maximum field gradient of about 0.01 T/mm.

Dipole magnets will be used to steer the beam through the transport system. Typical steering magnets would be approximately 10 mT transverse

field producing a deflection of about 20 mrad for an effective length of 30 cm.

The focal lengths of the quadrupoles are clearly different for the three mass components. This fact can be utilized to gradually remove the D_2^+ and D_3^+ beam by scraping them off on apertures in the beam pipe. Any deflecting or bending magnets will also separate the mass components. The combination of all of these components will effectively yield an output beam consisting of a single species D^+ .

Data Acquisition and Control

The data acquisition and control system could be centered around a computer system utilizing a computer of the size of a PDP-8/I with 8k core memory. This system would gather and log data from equipment in the high voltage dome and the accelerator beam line, control stepping motors and contact closures within the HV dome to adjust dome parameters, sense status contacts throughout the equipment, and initiate appropriate action in response to contact states.

Table I lists some of the parameters which would be sampled by a high speed multiplexer and A/D convertor. These parameters would be sampled periodically (once every second) and would be logged or acted upon as desired.

A variety of status events (see Table II), as represented by contact closures, would be monitored by the computer through the digital multiplex unit and interface. The computer and interface would be capable of providing manual or automatic control of the system operations listed in Table III. Outputs of the computer control system would also drive the control relays listed in Table IV for adjusting the high voltage supply.

Clearly, one of the most important parameters of the accelerator system is the dome voltage. This would be continuously monitored and displayed on a digital voltmeter. This parameter would also be logged with the other analogue parameters under program control.

Adjustment of dome parameters would be accomplished with Slo-Syn stepping motors and relay contact closures. A decoder in the dome would select the proper motor or relay in response to coded pulses received from the control system via the light or fiber-optic data links.

The computer would be programmed to operate in three basic modes:

1. Filament Conditioning Mode - each time a new filament is installed in the ion source it would be conditioned automatically by the computer.
2. Column Conditioning Mode - the accelerating column would be voltage conditioned automatically by the computer system after any maintenance which requires exposure of the electrodes to the atmosphere.
3. Operating Mode - this will be the general control mode for obtaining and maintaining the proper voltage and current conditions for a given operating condition.

Table I: Analogue Parameters to Be Monitored

1. Extractor Plate Current
2. Extractor Plate Voltage
3. Arc Current
4. Arc Voltage
5. Filament Current
6. Source Pressure
7. Ion Pump #1 Current
8. Ion Pump #2 Current
9. Dome Calibration Voltage
10. HV Supply Current
11. Measuring Resistor Oil Temp
12. Suppressor Current
13. Suppressor Voltage
14. Beam Line Pressure
15. Quadrupole #1 Current
16. Quadrupole #2 Current
17. Quadrupole #3 Current
18. Faraday Cup Current
19. Faraday Cup Voltage
20. Faraday Cup Water Flow
21. Faraday Cup Temperature
22. Radiation
23. Zero Check
- . etc.

Table II: HV Dome Communication Channels

Status Monitoring

1. Generator phase voltages
2. Extraction electrode supply
3. Ion pump #1 supply
4. Ion pump #2 supply
5. Arc variac at limit
6. Coil variac at limit
7. Arc down
8. HI limit
9. LO Limit

Stepping Motor Adjustment

1. Extraction electrode voltage
2. Arc current
3. Coil current
4. Filament current
5. D₂ gas flow

Relay Reset Actions

1. Extraction electrode supply
2. Ion pump #1
3. Ion pump #2
4. Arc start circuit
5. Arc trip-out circuit

Table III: Control Functions

1. Reset Extractor Power Supply
2. Start Arc
3. Reset Ion Pump #1
4. Reset Ion Pump #2
5. Trip Arc Power Supply
6. Increase Oscillator Output Voltage
7. Parameter Log
8. Column Conditioning
9. Filament Conditioning

Table IV: High Voltage Supply Controls

1. Coarse UP
2. Coarse DOWN
3. Fine UP
4. Fine DOWN
5. Trip OFF High-Voltage Supply Voltage

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Figure 1 - Schematic Layout of Accelerator Room

500KV 600MA COCKROFT-WALTON POWER SUPPLY

FIG. 2

Figure 3 - Sectional views of high voltage dome assembly.

Figure 4 - Block Diagram of Equipment in HV Dome

Figure 5 -. Cross Section of Duoplasmatron Ion Source

Figure 6 - Assembly of accelerating column vacuum vessel. Diagonal broken hatching denotes ceramic; all else is titanium except the outside rings which are aluminum. The electrode unattached in the figure is supported from the source assembly (not shown) and its potential is derived from the extractor power supply. The normal operating potentials in kV are listed on the right.

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T. H. Batzer	L-383
J. W. Beal (5)	L-382
A. W. Chesterman	L-384
J. C. Davis (2)	L-313
W. L. Dexter	L-728
T. J. Duffy	L-384
T. K. Fowler	L-382
G. W. Hamilton	L-386
R. E. Hester	L-382
V. K. Neil	L-382
J. E. Osher	L-386
L. L. Reginato	L-728
B. H. Smith	L-728
C. E. Taylor	L-382
R. V. Pyle, 5-117,	LBL
L. Smith, 50A-3115,	LBL
T.I.D. (15)	L-9

External

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