JUL 20 1965

MASTER

The Oak Ridge Multiple-Pass Injection Experiment, DCX-2 ¹

P. R. Bell
R. A. Gibbons*
G. G. Kelley

N. H. Lazar
J. F. Lyon
R. F. Stratton

Oak Ridge National Laboratory
Oak Ridge, Tennessee
U.S.A.

1. Introduction

The two DCX devices at Oak Ridge produce plasma of very high proton energy by dissociation of 600 kev molecular ions in a magnetic mirror containment geometry. [1],[2] The densities in both experiments were expected to be sufficiently high so that the ion loss rate would be dominated by scattering as in a controlled fusion device. These densities have not been reached as a result of the presence of strong microinstabilities which occur at the lower densities so far obtained. In DCX-2, the maximum density has been at least 8×10^9 ions/cm³. The effect of these microinstabilities is to spread the plasma energy both above and below the injected energy and also to cause radial and axial spread of the plasma. Other high energy injection devices have been plagued, in addition, by low frequency hydromagnetic instabilities. [3],[4],[5] These lower frequency phenomena have been shown to be controlled by proper shaping of the containing magnetic geometry (minimum B) or by applying suitable electric fields between the plasma and the walls. [3],[5],[6],[7] Such complications have, so far, been unnecessary in the DCX devices since the low frequency phenomena are not present.

Both DCX devices produce plasma of higher energy than any of the other high energy injection experiments. The mean energy in DCX-2 is sometimes greater than 800 kev. In DCX-1 it is about 300 kev. All of the other experiments of this type have much lower injection energies and produce plasma of less than 100 kev mean energy. [3],[4],[5],[8]

2. Description of DCX-2

The principle of injection and the design parameters of DCX-2 were described in the Salzburg Conference. [2] The device in its present form is shown in Fig. 1. The overall length is 8.2 meters and the central region between the mirrors where the trapping occurs is 2.65 meters. The central tank is approximately 1 meter in diameter. The beam is injected near one end of the central region at a place where the field is slightly depressed. The injection angle of about 7.5° is chosen so that the first turn of the 600 kev molecular ion beam misses the injection duct. This duct shields the beam from the main field and is compensated to cancel approximately the disturbance it creates in the field. Over a region of about 70 cm either side of the midplane the field may

¹ Research sponsored by the U. S. Atomic Energy Commission under contract with the Union Carbide Corporation.

* Deceased

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

be made flat to within about ± 2 gauss. It has been found, however, as will be discussed below, that the maximum plasma density occurs when the field at the midplane is slightly depressed. The magnetic field in the mirror throats is 39 kG with a mirror ratio of 3.3. All field currents can be held constant during an experiment to about 0.3%. The beam is operated steadily or it may be pulsed at any convenient repetition period -- usually about 1 per sec with 50% duty cycle.

The accelerator tube shown in Fig. 1 makes use of cast epoxy skirts to provide a sufficiently long external voltage breakdown path. [9] The internal electrode shapes are designed to eliminate trapping regions for electrons produced in crossed electric and magnetic fields which under some conditions can cause steady current drains, and to provide rapid cleanup. Although molecular ion currents of about 100 ma have been produced at 600 kev through a duct configuration like that in DCX-2, the maximum DCX-2 current has been limited to 55 ma apparently because of incomplete shielding of the stray magnetic field.

The diagnostic instruments which have provided the most information concerning the plasma in DCX-2 are listed below.

- 1) Foil-covered Faraday cups for measurement of the current of energetic neutrals from the dissociation of the molecular ion beam and from charge exchange. The attenuation of the foils normally used (0.25 μ nickel) begins at 150 kev and is 100% at about 50 kev. Gated integrating amplifiers are used to determine the total charge collected by these detectors after the molecular ion beam has been turned off.
- 2) Collimated silicon barrier detectors. These detectors produce pulses proportional to the energy of the incident particles and are used with a multichannel pulse-height analyzer to measure the energy distribution of charge exchange neutrals leaving the plasma. They are collimated typically by means of a 5 μ slit and 20 μ pinhole suitably spaced to accept a fan of particles 40° high by 0.15° wide. This geometry is indicated schematically in Fig. 2.
- 3) Radial electric probes and magnetic loops are used with narrow and wide band rf spectrometers for measurement of the rf in the plasma region. One of the spectrometers can sweep a range of 2 Gc from 0 to 42 Gc. A second sweeps up to 3 mc from 0 to 25 mc and a third 10 to 100 mc at a sweep frequency of 10 kc.
- 4) Various calorimeters. The power in the beam and plasma striking the injector is routinely monitored. The remainder of the accelerator beam power is measured by separate water circuits inside the beam duct. A probe may be inserted near the injector to measure the injected beam power.
- 5) Gridded probes for measurement of cold plasma characteristics. Two or three grids in front of a collector are used in either plane or hemispherical geometry. Voltages are applied to the grids to separate the ions and electrons, and the collector voltage is swept to measure the energy of either ions or electrons.

3. Experimental Results

The experiments with DCX-2 may be divided into two main classes:

- (1) Dissociation of the molecular ion beam by the background gas and secondary

plasma. Roughly 40% of the protons produced are in orbits which will not strike the injector when the orbit precesses about the axis of the machine.

(2) Enhanced dissociation of the molecular ion beam in a dense high vacuum arc. The arc is situated along flux lines which pass through the molecular ion helix diametrically opposite the injection point. All protons formed in the arc must be scattered radially more than one larmor radius to strike the injector. Both lithium and hydrogen arcs have been used for this purpose. Most of the experiments performed in DCX-2 in fact have been in the presence of a lithium arc.

Lithium Arc Experiments. The highest densities yet observed in DCX-2 have been produced with lithium arc dissociation. The arc operates between electrodes spaced approximately 6 meters placed outside the mirror coils. Lithium is stored in a stainless steel boiler which is heated electrically to temperatures between 600-700°C. A large diameter tube connects the boiler with the tantalum anode which has a tungsten plug to terminate the arc. The temperature of the anode is independently controlled. A filamentary tungsten cathode is used so that the arc may be turned on and off easily. The effective cathode cross-section is 0.45 x 1.0 cm. The arc normally is operated at approximately 20 amperes and a voltage of 180 volts 2.5 cm from the field axis opposite the injector. The injector is positioned so that the 26.5 cm diameter molecular ion orbits pass through the expected position of the main arc column (Fig. 2). From probe and spectroscopic evidence the arc density has been estimated to be 5×10^{13} ions/cm³. A large radial transport of lithium ions is observed which is found to increase when the hot plasma is present.

The total number of energetic particles in the plasma can be determined from the time integral of the charge exchange flux after the beam is shut off. If losses other than charge exchange occur after the beam is turned off the measurement is an underestimate of the trapped particle number. To obtain a density the mean radius of the plasma is taken as 15 cm. The results must include a correction for low energy particles which are absorbed in the nickel foil. The correction amounts approximately to a factor of two but cannot be determined exactly because of incomplete knowledge of the energy spectrum at low energies. An oscillograph trace taken during a typical beam turnoff experiment is shown in Fig. 3. Here the integral of the charge exchange flux is plotted as a function of time. The best estimates of plasma density yield values of 8×10^9 energetic ions per cm³ trapped in the central volume of the main magnetic field with an injected H₂ beam current of ~ 40 ma. Experiments have also been carried out with the arc 7.5 cm from the axis and on the axis itself with quantitatively somewhat different results but qualitatively similar behavior. The mean lifetime of the particles in the plasma cannot easily be evaluated from the time dependence of either the current or the current integral since the current decay is not a simple exponential. The trapped particles have a very wide energy distribution and the density of particles which charge exchange with them changes with time after the beam is turned off. There is also evidence of continuing energy mixing. All of these effects influence the shape of the decay curve.

A second major source of information concerning the plasma ions is derived from the collimated surface barrier silicon detectors. Data typically are taken by scanning across the plasma volume for a period of several minutes while the beam is being pulsed on and off continuously at a one second repetition rate. The pulse-height distribution thus obtained, when corrected for the charge exchange rate as a function of energy, yields the energy distribution of the contained particles. A typical spectrum with high plasma density is

shown in Fig. 4. A scan in angle made with the slit perpendicular to the field axis would show only two peaks if the trapped particles retained the angle at which they were injected. Figure 5 shows this behavior at low beam currents. When this beam current is raised above several milliamperes, however, a prominent peak appears at zero degrees. The peak shown in Fig. 5b, observed with ~ 40 ma injected H_2^+ beam current corresponds to particles with a spread in angle of less than $\pm 2^\circ$. Such particles are reflected by the very slight rise in the magnetic field at ± 70 cm from the midplane. The intensity of this peak and in general the trapped density is maximized by varying the shape of the field slightly. A field dip of only ~ 20 gauss over the central 140 cm produces the maximum density. Variations of only a few gauss from this field shape result in a significantly smaller trapped density.

From the angle corresponding to the maxima of the side peaks observed in scans with selected total energy, the axial energy of the particles is determined (Fig. 6). It is apparent that the average axial energy is almost unchanged from the injected axial energy, in spite of the very large change in total energy.

Energy distributions were observed for the particles in the central peak and similar data were taken for the side peaks. The results, corrected for the charge-exchange cross sections, are shown in Fig. 7. It is clear that the highest energy particles are contained in the plasma group with the nearly zero axial energy.

An indication of the radial distribution of the plasma is obtained from angular scans with the slit aligned parallel to the field axis. Such an angular distribution for the group with the higher axial energy was obtained using a bar placed to intercept particles with pitch angles of less than $\pm 3^\circ$. The particles with the larger axial energy are restricted to a radius of less than ~ 15 cm. This limit is determined by the position of the injector and the fact that the particles precess about the machine and therefore are intercepted by the injector as they spread radially.

From the intensity of the observed current in the central peak and the longer lifetime of these more energetic particles, it is apparent that most of the density in the plasma is associated with this group. Typical angular scans with the collimator slit parallel to the field axis for the higher energy particles indicate they are spread in radius to ~ 30 cm with a mean value of ~ 15 cm. Despite their large radial extent, these particles do not strike the injector since they are reflected by the slight field increase inside the injector position.

Quantitative estimates of the average lifetime of the charge-exchanging particles may be determined by averaging the energy-dependent lifetime over the observed energy distribution; i.e., the mean lifetime for charge-exchange, is $\bar{\tau}_{cx} = \frac{\int_0^\infty I_{cx}(E) (n_0 \sigma_{cx} v)^{-1} dE}{\int_0^\infty I_{cx}(E) dE}$ where n_0 is the density of charge-exchange centers, $I_{cx}(E)$ is the charge-exchange current per unit energy interval, σ_{cx} is the charge-exchange cross section at a given energy, and v the velocity of the energetic particle. Measurements of σ_{cx} are available only to 1 Mev [10] and have been extrapolated to higher energy. The assumption is made that the charge-exchanging centers have cross sections equal to the nitrogen cross section. The values of $\bar{\tau}_{cx}$ determined in this way may be multiplied by the total charge exchange current to yield a density estimate during equilibrium. The values so obtained, assuming n_0 to be the neutral

particle density obtained by pressure measurement, are a factor of 5 to 10 higher than the values obtained from the time integral of the neutral flux after the beam is turned off. The disagreement between these two measurements of plasma density is considered to be the result primarily of a high density of cold plasma in the volume, which increases the charge-exchanging density.

The cold plasma density may be estimated from the dissociation current observed to the energy analyzer from positions outside the arc in the region of the cold plasma. Using the nitrogen dissociation cross section one obtains a density of $\sim 5 \times 10^{10}$ ions/cm³. The distribution and density of these cold ions also may be estimated from the saturation current to a gridded probe inside the plasma chamber but outside the region where the energetic ions are trapped. An order of magnitude agreement is obtained. Retarding potential measurements using these gridded probes show the electron energy and plasma potential to be below 50 ev. The axial energy of the ions varies with radius falling from 250 ev near the axis to less than 20 ev at 15 cm.

Figure 8 shows a series of measurements taken with the collimator slit of the energy analyzer aligned parallel to the field axis when specific energy ranges were electronically selected. Assuming the particles precess uniformly about the axis of the field, one would expect to find a distribution of current as a function of detector angle symmetric about a point displaced one larmor radius from the axis. In fact, the observed distribution is asymmetric. We believe the asymmetry to be due to non-uniform distribution of the cold ions.

The peaks observed in the parallel slit scans produced by dissociation of the direct and reflected molecular ion beams in the cold plasma and neutral gas also are used to estimate the percentage dissociation of the beam. The results vary from $\sim 50\%$ to greater than 90% dissociation depending on the arc conditions. The power to the water-cooled target on the injector, however, is typically 60-90% of the total beam power. The additional power appears to be due to the loss to the injector of protons from the plasma group with the large axial momentum. From the observed charge exchange flux, in some cases as much as $3/4$ of the injected beam current appears to have been lost by this mechanism. At plasma densities of 4×10^9 ions/cm³ with an injected beam of 25 ma, approximately half of the particles were accounted for by charge exchange flux. For beam currents below 25 ma, the energetic ion density decreases approximately linearly with injected current. As the current is raised above this value there is evidence that the density does not increase proportionately. Insufficient data concerning the nature of the arc and the change in composition of the background plasma at the higher currents makes it uncertain, however, that a density limit determined by plasma instabilities has been reached.

Radiofrequency measurements have been made using both electric field sensitive antennas and magnetic loops. These probes show evidence of electric and magnetic fields at the ion cyclotron frequency and many of its harmonics. For example in Fig. 9a is shown the frequency spectrum to 2 Gc observed with a radial electric probe, and harmonics as high as the 100th are seen. The number of harmonics and the shape of the harmonic pattern are related both to the energetic ion plasma density and the density of cold plasma. The radiofrequency persists after the beam is shut off for times as long as several seconds. Measurement of the energy spectrum during this time shows a continuing production of low energy ions. This experiment is

additional evidence that the energy spread of the plasma particles is related to the presence of the rf.

Another odd characteristic of the radiofrequency signals is found in detailed studies of the structure of the individual harmonic peaks. The width of the peaks is quite large, of the order of 700 kc at high densities, and the shape and frequency of the peaks change when the beam is turned off. Figure 3 shows the spectrum in the vicinity of the ion cyclotron frequency as a function of time. It is seen that the frequency varies from slightly below the ion cyclotron frequency up to that value but apparently never exceeds the ion cyclotron frequency.

Careful examination of the low frequency end of the spectrum shows no evidence of low frequency oscillations of the plasma as is seen in other high energy injection machines [3], [4], [5]. Unexplained fluctuations in the current to the neutral particle detectors have been noticed. These fluctuations are related to variations in the low density, large axial energy plasma and are not seen in the charge-exchange flux from the plasma with low axial energy. The fluctuations are found to be unrelated to energetic charged particles escaping to the walls. In fact, although pulses from energetic charged particles are seen with gridded probes outside the trapped plasma, these are independent of plasma density and do not appear to represent a significant loss. Axial correlation of these gridded probe signals is absent. This fact and the lack of low frequency electric oscillations indicate that flute-like disturbances are not present.

Hydrogen Arc Experiments. The parallel slit scans using the energy sensitive detector looking at the plasma produced with lithium arc dissociation show that the loss by charge-exchange is at least as much from the arc as it is from the background gas and cold ions. A hydrogen arc has been used to eliminate this loss. Unfortunately the lowest background pressure attained thus far with this arc however, is quite high (3×10^{-6} mm Hg in DCX-2) because of plasma flutes. [11] These arc flutes have been identified by probe correlation measurements.

An evaluation of the usefulness of the arc as a dissociation medium is complicated by the possible influence of several effects. The percentage dissociation of the molecular hydrogen ion beam and the observed trapped plasma density increase with increased gas feed to the arc. It is not clear, however, that the increase in observed density is due only to increased dissociation since the partial pressure of hydrogen in the plasma region also is increased. As will be explained below an increase in hydrogen pressure in the same pressure range with gas breakup also increases the density of the trapped plasma.

The perpendicular slit scans of the plasma produced by hydrogen arc breakup show that the group of particles with low axial energy is present also with the hydrogen arc. The parallel slit scans, however, as expected, show no peak in the direction of the arc indicating that it does not contribute appreciably to charge-exchange loss. Integrals of the charge-exchange flux give densities of 1 to 2×10^9 ions/cm³ at a gage pressure of 5×10^{-6} mm Hg. The rf seen with the hydrogen arc is qualitatively the same as with the lithium arc. The arc is formed between a long hollow copper anode and a hollow tungsten cathode [12], [13]. Under the condition of lowest gas flow, it operates at about 80 amperes at 200 volts with a gas flow of 0.25 atm cm³ of hydrogen per second.

4. Gas Dissociation

Experiments with gas dissociations at base pressure ($\sim 2 \times 10^{-7}$ mm Hg) show significantly lower density than is obtained with the arcs ($\sim 1 \times 10^8$ ions/cm³). As expected, the charge-exchange current increases and the plasma density remains approximately constant as the pressure is increased by introducing N₂ gas. The decreased lifetime is offset by an increased trapping rate although an exact balance is not expected due to variations in energy mixing. When hydrogen gas is added, however, the plasma density increases, reaching a maximum value of 5×10^8 ions/cm³ at a gage pressure of 1.8×10^{-5} mm Hg. The energy of the trapped plasma spreads and the mean energy rises. Figure 10 shows the variation of density and the mean energies of this plasma as a function of gage pressure. Perpendicular slit scans did not show a central peak, however, during this experiment, although a small central peak usually is observed at the optimum field setting at base pressure. Electric probe measurements show an rf spectrum differing somewhat from those obtained with arc breakup; see Fig. 9b. The plasma potential at base pressures with gas dissociation is much higher than in the arc experiments. The potential varies rapidly in the region of several hundred volts positive relative to the walls, the electron energy is observed to vary between 50 and 100 ev; the ion energies between 45 and 130 ev. At the highest densities at elevated pressure, ion and electron energies are considerably higher.

5. Discussion of Results

The plasma in DCX-2 is quite complex, consisting of usually two groups of fast ions and a relatively higher density of colder ion components. In every case the highest densities are associated with a broad spread of energy and a mean energy many times the injected energy. With arc breakup the particles having the widest energy spread have a very small axial energy, implying heating by electric fields very nearly perpendicular to the axis. With gas breakup, however, under the condition of a high background pressure of hydrogen, the broad energy distributions can be obtained without the appearance of this separate perpendicularly oriented group. The lifetime is long in both cases in spite of high gas pressure because of the accumulation of very high energy ions.

The pressure in the plasma region is not reduced by plasma pumping as much as had been expected. Apparently the cold hydrogen ions, and to a lesser extent heavier ions, are being heated by interaction with the fast ions. If the cold ions are heated more quickly in the perpendicular direction than they can scatter axially, they are prevented from flowing out of the plasma region along the flux lines through the mirrors. Eventually they are lost by charge-exchange and returned as neutral gas particles.

The mechanism by which the group of particles of zero average axial energy is produced is not understood. Several mechanisms have been suggested. One possibility is a form of streaming interaction among the counterstreaming particles having the initial axial energy. A second possibility is that cold hydrogen ions are resonantly heated to high energy by essentially perpendicular fields at a sufficient rate to overcome charge-exchange losses. The difficulty in choosing between the various possible models lies in the imprecision of measurement of plasma properties. These difficulties must be resolved by improved measurement techniques.

The authors gratefully acknowledge the technical assistance of J. S. Culver, S. M. Decamp, J. C. Ezell, A. J. Wyrick, E. C. Moore, T. F. Rayburn, and C. W. Wright. In addition we take pleasure in acknowledging the work of J. E. Francis in the development of the filamentary lithium arc and the improvements in the hydrogen arcs used in DCX-2 and the major contributions of O. B. Morgan and R. C. Davis to the development of the injector. We would like to thank Mozelle Rankin for computational assistance in many phases of the design of experiments. We would also like to express our appreciation for helpful discussions with T. K. Fowler, J. L. Dunlap, and H. Postma. We would like to thank A. H. Snell for continued encouragement and assistance.

1. BARNETT, BELL, LUCE, SHIPLEY, and SIMON, Proceedings of Second UN International Conference on Peaceful Uses of Atomic Energy 31, 298 (1958).
2. BELL, KELLEY, LAZAR, and MACKIN, Nuclear Fusion (Supplement) Part 1, 251 (1962). Full details of the DCX-2 experiments are found in the Thermonuclear Division Semiannual Reports ORNL 3239, 3315, 3392, 3472, 3564, 3652, 3760, and 3836.
3. BOGDANOV, GOLOVIN, KACHERYAEV, and PANOV, Nuclear Fusion (Supplement) Part 1, 215, (1962).
4. DAMM, FOOTE, FUTCH, and POST, Phys. Rev. Letters 10, 323 (1963).
5. KUO, MURPHY, PETRAVIC, and SWEETMAN, Phys. Fluids 7, 988 (1964).
6. BAIBORODOV, IOFFE, PETROV, and SOBOLEV, Atomnaya Energiya 14, 143 (1963). (Translation: Soviet Physics, Atomic Energy 14, 459 (1964)).
7. DAMM, FOOTE, FUTCH, GORDON and POST, Phys. Rev. Lett. 13, 464 (1964).
8. G. GOURDON and F. PREVOT, Nuclear Fusion (Supplement) Part 1, 265, 1962.
9. G. G. KELLEY, O. B. MORGAN, Minutes, 1964 Linear Accelerator Conference, p. 456, MURA 714, UC-28, TID-4500.
10. BARNETT, RAY, and THOMPSON, Atomic and Molecular Collision Cross-Sections of Interest in Controlled Thermonuclear Research, ORNL-3113 (Rev) (1964).
11. R. A. GIBBONS, N. H. LAZAR, Phys. Rev. Letters 13, 703 (1964).
12. R. A. GIBBONS and R. J. MACKIN, Proceedings Fifth International Conference on Ionization Phenomena in Gases, Munich 1961, Vol. II, 1769, North Holland Publishing Company.
13. FRANCIS, BELL, LAZAR, GIBBONS, ORNL Report 3760, p. 52.

Figure Captions

- Fig. 1 Longitudinal section through DCX-2. Rings of detector ports are located in the spaces between the coils.
- Fig. 2. Transverse section through DCX-2 showing possible locations for various detectors. The energy analyzer is shown with the slit perpendicular to the axis.
- Fig. 3. RF spectrum and foil neutral detector integrals vs. time after beam turn-off. Sweep speed 0.1 sec/cm. Upper trace, integral at center of machine with 3.3×10^{-10} coulomb/cm. Lower trace, integral of the sum of five detectors along the machine axis with 10^{-9} coulomb/cm. Trace is intensity modulated by the amplitude of the rf.
- Fig. 4. Energy spectrum of charge-exchange neutral particles from the DCX-2 plasma and the corresponding energy distribution of the trapped plasma as seen from the center of the machine. Mean energy of trapped protons is 847 kev. Symbols at 10° indicate no counts.
- Fig. 5. Pitch angle distribution of charge-exchange neutrals as seen from the center of the machine. Results at low beam current (0.3 ma) are shown in (a) and at high beam current (40 ma) in (b).
- Fig. 6. Axial energy of the side peak maxima for different total ion energies.
- Fig. 7. Energy distribution of the plasma components with high and low axial energy.
(a) The low axial energy component.
(b) The higher axial energy component. The circles and crosses distinguish between the distributions seen looking toward and away from the injector respectively. The detector was in the mid-plane of DCX-2. Symbols at 10° indicate no counts.
- Fig. 8. Energy-resolved parallel slit scans of the DCX-2 plasma as seen from the center of the machine. The detector is in the position shown in Fig. 2. The peaks seen at 27° and 31° are due to 300 kev dissociation neutrals from the beam and are separated because of precession of the molecular ion orbit during reflection. These peaks are also seen in the scans not including 300 kev because of scattering in the slit, resolution in the detector and the occurrence of random sum lines. The peak near zero degrees is from charge exchange in the lithium arc.
- Fig. 9. Frequency spectrum from 100 mc to 2 Gc observed with a radial electric probe near the mid-plane in DCX-2. (a) Hydrogen arc dissociation. (b) Gas dissociation.
- Fig. 10. Density and mean energy of the trapped plasma produced by gas dissociation as a function of pressure. The pressure was raised by adding hydrogen.

LEGEND

1. ELECTROMAGNET COILS
2. MAIN VACUUM TANK
3. COOLED LINER
4. DIFFUSION PUMP AND BAFFLE
5. ION SOURCE AND ACCELERATOR
6. INJECTION SNOOT
7. PLASMA
8. ARC ELECTRODES
9. ACCELERATOR X-RAY SHIELD
10. DIAGNOSTIC PROBE (ONE OF MANY)
11. TITANIUM EVAPORATOR
12. BEAM TARGET

Fig. 1 Longitudinal section through DCX-2. Rings of detector ports are located in the spaces between the coils.

Fig. 2. Transverse section through DCX-2 showing possible locations for various detectors. The energy analyzer is shown with the slit perpendicular to the axis.

Fig. 3. RF spectrum and foil neutral detector integrals vs. time after beam turn-off. Sweep speed 0.1 sec/cm. Upper trace, integral at center of machine with 3.3×10^{-10} coulomb/cm. Lower trace, integral of the sum of five detectors along the machine axis with 10^{-9} coulomb/cm. Trace is intensity modulated by the amplitude of the rf.

Fig. 4. Energy spectrum of charge-exchange neutral particles from the DCX-2 plasma and the corresponding energy distribution of the trapped plasma as seen from the center of the machine. Mean energy of trapped protons is 847 kev. Symbols at 10^0 indicate no counts.

Fig. 5. Pitch angle distribution of charge-exchange neutrals as seen from the center of the machine. Results at low beam current (0.3 ma) are shown in (a) and at high beam current (40 ma) in (b).

ORNL-DWG 64-9097A

7/15/64

Fig. 6. Axial energy of the side peak maxima for different total ion energies.

Fig. 7. Energy distribution of the plasma components with high and low axial energy.

- (a) The low axial energy component.
- (b) The higher axial energy component. The circles and crosses distinguish between the distributions seen looking toward and away from the injector respectively. The detector was in the mid-plane of DCX-2. Symbols at 10^0 indicate no counts.

Fig. 8 Energy-resolved parallel slit scans of the DCX-2 plasma as seen from the center of the machine. The detector is in the position shown in Fig. 2. The peaks seen at 27° and 31° are due to 300 keV dissociation neutrals from the beam and are separated because of precession of the molecular ion orbit during reflection. These peaks are also seen in the scans not including 300 keV because of scattering in the slit, resolution in the detector and the occurrence of random sum lines.

(a)

(b)

Fig. 9. Frequency spectrum from 100 mc to 2 Gc observed with a radial electric probe near the mid-plane in DCX-2. (a) Hydrogen arc dissociation. (b) Gas dissociation.

Fig. 10. Density and mean energy of the trapped plasma produced by gas dissociation as a function of pressure. The pressure was raised by adding hydrogen.