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LAWRENCE LIVERMORE LABORATORY

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PROGRESS TOWARDS MIRROR FUSION REACTORS

R. F. POST

July 25, 1973

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As the CTR Position Paper states, the open-ended geometry of magnetic mirror systems offers important potential reactor engineering advantages. One of these is compactness: mirror reactors could be small but with high power density and intermediate power output. We visualize mirror reactors as devices in which the high temperature plasma is produced and maintained against the normal leakage through the mirrors by a continuous input of heating power supplied by energetic neutral atom beams. The use of mirrors also frees mirror machines from one of the practical problems of fusion reactors - contamination of the fusion plasma by impurity atoms. Except under unusually bad circumstances impurities leak out through the mirrors essentially as rapidly as they enter the plasma.

We believe we have a clear picture of what must be accomplished en-route to mirror reactors, and we already have some milestones behind us. Our first priority remains to prove adequately stable plasma confinement at high plasma densities and temperatures. We also need highly efficient high intensity neutral beam sources to heat the plasma and we must learn how to recover energy with high efficiency from the plasma by direct conversion. Finally, we will need to know how to design high-field superconducting magnets of complex shape. We have work going forward at the Lawrence Lab in all of these areas. Today I would like to briefly review recent progress in two of these areas: namely, plasma confinement at high

plasma density and the development of intense highly focussed neutral beams and their injection into plasmas in our mirror machines. At the conclusion I would like to mention a concept that we believe could lead to a compact high power density D-T burning mirror reactor - one that would exploit the potentialities of high power density neutral beam injection.

In recent experiments in the Livermore 2XII high plasma density pulsed mirror experiment we have seen a particularly encouraging result: By carefully controlling the plasma injection conditions we have achieved plasma confinement at high densities that comes so close to the theoretical ideal value for a stable plasma that we cannot tell the difference. Furthermore this plasma is most stable at its highest density - and we believe we have a theory that explains this observation. The present 2XII plasma is not quite as dense as needed for a reactor and is too low in temperature because of limitations in the present experiment. Nevertheless the same theory that agrees with the present results predicts what plasma conditions would be required for stability in mirror reactor.

In 2XII we have also recently successfully injected a 10 ampere 200 kilowatt pulsed neutral atom beam into the plasma with no observable deterioration in plasma stability despite the the high power level. These neutral beam sources were developed for us by the Lawrence Berkeley Laboratory using computer-optimized designs. We are now jointly developing 50 ampere and 200 ampere - that is 1 megawatt and 4 megawatt - modules and are preparing to modify the 2XII magnet chamber to accept several such beams - up to 600 amperes - that is, up to 12 megawatts of beam heating power into the plasma.

We are also preparing to modify the injection system of our other

major mirror experiment at Livermore, Baseball II, to use these high current beams. Baseball II has the largest superconducting magnet now in use in fusion research. Although Baseball II has demonstrated the stable confinement - for over 1 second - of a low density plasma created by a low current neutral beam source - we plan to accelerate our rate of progress toward high plasma densities by introducing the new high current neutral beam sources as soon as possible. To speed the rate of buildup of the plasma density we are also considering the use of "startup" plasma targets, possibly small laser-heated plasma targets of the kind being studied at United Aircraft.

Finally, we have begun paper studies of a mirror reactor concept based on pushing neutral beam heating to its limit. The idea is to have a compact mirror machine through which would pass a column of high density, low temperature tritium plasma created by plasma sources outside the mirrors. This column would only be a few centimeters in diameter and would not need to be confined by mirrors. The column would be bombarded by intense beams of energetic deuterons from an array of neutral beam sources - several thousand amperes. The following should then occur: The deuterons would be ionized by impact on the plasma column and become trapped between the mirrors. The intense heating power that they would deliver to the tritium plasma column would heat it to fusion temperatures so that fusion reactions will occur with the trapped deuterons. The process is predicted to lead both to much stabler plasma conditions and to an improved power balance as compared to our usual ways of operating a mirror system. We also believe this idea could fill a shorter term need of the fusion program as a whole - a high intensity D-T neutron source for fusion reactor wall studies. Though

these ideas are new and therefore as yet untried we believe they represent a very promising approach.

We realize that we still have much to accomplish, but we believe the recent scientific and technological advances in mirror research have clearly defined for us a possible path to mirror fusion reactors.

Photo Captions

- 1) Photograph of a portion of a 10 ampere, 20 kilovolt (200 kilowatt) pulsed neutral beam source, showing the slots through which the beam ions are accelerated before they are neutralized.
- 2) A computer printout of the computer-optimized shapes of a slotted extraction system of the type shown in Fig. 1. Computed paths of the ions are shown, illustrating the degree of focusing achieved. Ions move from right to left, starting at the source plasma surface from which they are extracted.
- 3) Photo of a portion of a 50 ampere, 20 kilovolt (1000 kilowatt) neutral beam source under development at the Lawrence Berkeley Laboratory for use in the 2XII and Baseball II experiments.
- 4) Schematic of the 2XII facility Mirror Experiment. The plasma is injected at the right hand end of the vacuum chamber and flows along uniform magnetic field lines generated by currents in the d.c. magnets. Part of the injected plasma is trapped in the center of the machine, compressed and heated by properly programming the currents in the gate and compression magnets. Plasma which is not initially trapped or which subsequently escapes the confining magnetic field is adsorbed on clean titanium surfaces in the end chambers.

The confining magnetic field is generated by currents of 1.5 million amperes flowing in the single copper conductor of the compression magnet. This magnet, consisting of two C-shaped coils oriented at right angles to each other and centered about a common point, provides a magnetic field which has a low point at the center so that the field increases in every direction away from the center. Fields with this

property are known as minimum-B fields. Such fields inhibit the development of a class of particle loss processes known as hydromagnetic instabilities as well as confining single ionized particles.

- 5) Artist's sketch of the Baseball II plasma confinement experiment. The superconducting "baseball" magnet hangs in the large vacuum tank. An intense neutral beam is generated in the ion source (far right) and neutralizer section, injected through the central region of the magnet, and the unionized beam is deposited in the "burial" chambers at the left. Particles trapped in the central region are confined by the strong magnetic field and accumulate over a period of seconds to form a dense plasma.
- 6) Illustrative plasma parameters for a "breakeven" two-component mirror system.

Figure 1

XBL 7111 - 4665

Figure 2

Figure 3

THE 2X II FACILITY

Figure 4

BASEBALL II

SUPERCONDUCTING NEUTRAL INJECTION EXPERIMENT

Figure 5

Parameters for a "Breakeven" ($Q = 1$) Two-Component Mirror Device

Injection Energy	200 keV
Electron Temperature	4 keV
Tritium Plasma Density	10^{16} cm^{-3}
Plasma Column Diameter	2 cm
Plasma Column Length	10 m
Injection Current (equiv. amps)	2000 A
Confinement Time of Deuterons	1 msec
Fusion Power Released	400 MW

Figure 6

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