274
8/15/79
BNL 50985

LD. 2999

MASTER

ANNUAL REPORT OF THE BROOKHAVEN NATIONAL LABORATORY
HEAVY ION FUSION PROJECT FOR THE PERIOD
1 OCTOBER '77 - 1 OCTOBER '78

FEBRUARY 1979

ACCELERATOR DEPARTMENT
BROOKHAVEN NATIONAL LABORATORY, ASSOCIATED UNIVERSITIES, INC.
UNDER CONTRACT NO. EY-76-C-02-0016 WITH THE
UNITED STATES DEPARTMENT OF ENERGY

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.

BNL- 50985

UC-21

(Inertial Confinement Fusion - TID-4500)

ANNUAL REPORT OF THE BROOKHAVEN NATIONAL LABORATORY

HEAVY ION FUSION PROJECT FOR THE PERIOD

1 OCTOBER '77 - 1 OCTOBER '78

FEBRUARY 1979

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or 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.

ACCELERATOR DEPARTMENT

BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

88

ANNUAL REPORT OF THE BROOKHAVEN NATIONAL LABORATORY
HEAVY ION FUSION PROJECT FOR THE PERIOD 1 OCTOBER '77 - 1 OCTOBER '78

This report is divided into three parts. The first deals with the results of an analysis of the fusion problem in general, and heavy ion inertial fusion in particular. The second portion deals with the progress being made in the design and development of high current, high "brightness" pre-injectors and linear accelerators. The third portion deals with some experiments with space charge neutralization, bunching, etc.

I. SYSTEMS STUDIES:

Heavy Ion Accelerators for Inertial Confinement Fusion were investigated and the results may be summarized as follows:

1. A heavy ion linear accelerator, with accumulators and bunchers, can produce beam for around \$5/watt of average beam power. The threshold for economic operation is around 50-100 MW of average beam power. No systems have been proposed that come within a factor of 10 of this cost/watt. Furthermore, the efficiency of the linac/accumulator system is about 40%.

2. If a heavy ion accelerator was used as an ignitor for an inertial fusion electric power station, the ignitor portion of the plant, assuming 33% fusion energy to electric conversion would be $15/Q$ \$/watt, where Q is the pellet gain (fusion energy out/beam energy in). Q 's in the range of 50-100 would result in igniter costs which would be a reasonably small fraction of the cost of present power plants (around 1\$/watt).

3. Inertial Confinement Fusion cannot compete with either Light Water Reactors (LWR's) or Liquid Metal Fast Breeder Reactors (LMFBR's) in the production of electricity. The LLL/Bechtel study⁽¹⁾ showed that without taking account of ignitor or pellet costs, the cost of a Fission-Fusion hybrid plant was 2.5 times higher than a LWR. Similar results have previously been obtained for magnetic fusion. Hancox⁽²⁾ summarized the results of a large number of system studies of magnetic fusion devices. All of them were more than twice the cost of a similarly costed LMFBR.

4. Tritium and/or Pu production for the Division of Military Application (DMA) has been identified as the most probable application of fusion generally, and inertial fusion in particular, to become competitive with

rent production costs. Since the principal value of fusion is as a neutron producer, special emphasis should be placed upon systems that minimize the tritium breeding requirement.

5. The most probable civilian application of fusion to achieve economic viability is fissile fuel production for LWR's or LMFBR's. Since Fusion electric plants will cost much more than nuclear plants, they could only be competitive if the price of nuclear fuel rose to very high levels. The ability to produce fissile fuel with a fusion plant would prevent nuclear fuels from rising to the level where fusion could compete as a heat source for producing electricity. Furthermore, the capital cost of a facility which produces only fissile fuel will likely be considerably less than that of a comparable plant designed for the high temperature necessary for steam generation.

6. The tritium problem has been considerably understated in both the Magnetic and Inertial Fusion programs.

a. The technology does not exist for handling large amounts of tritium at the temperatures to be found in a steam generator.

b. The utility of tritium as an ingredient in modern nuclear weapons has also been understated. The current policy of keeping the technology for producing large amounts of tritium secret is likely to continue. This will have a serious impact on the development of pilot plants, prototypes, etc.

7. There are two major deficiencies in the inertial fusion program.

a. There is no rational basis for estimating the costs of pellet manufacture. Present costs (around \$10,000 a piece) are so high, that it is

vitally necessary to exhibit the design of a plausible pellet fabrication facility which will get the cost down to a reasonable level. Naive remarks about transistors are no substitute for an engineering cost estimate of a pellet factory.

b. Realistic engineering designs need to be done for the explosion chambers. A plausible system for handling the blast, and the tritium containment, etc. should be designed, at least up to the completion of Title I.* Since such a system will undoubtedly involve the production and handling of large amounts of tritium, it will be classified. The Savannah River Laboratory is the natural place to pursue the design study.

II. ACCELERATOR DEVELOPMENT:

A conceptual design of a heavy ion linear accelerator was developed⁽³⁾ which minimized the technological extrapolation needed to build a powerful ICF driver. A novel feature of the accelerator was the 2 MHz linear accelerator. The lowest frequency heavy ion linacs currently in operation are about 10 times higher in frequency. In FY '78 we have completed the design, and started the construction of a prototype 2 MHz heavy ion linac capable of accelerating Mercury with a velocity = $.002c$. A dominant feature of the design is the external, high Q, 2 MHz resonator.⁽⁴⁾ Another novel feature of the design is the electrostatic quadrupole focusing system within the drift tubes.

*A Title I design is a sufficiently detailed design that reliable cost estimates can be made from it, and demonstrates conceptually how the facility could be built. No R&D would be required to go to the detailed engineering design (Title II, consisting of construction drawings, specs, etc.).

Electrostatic focusing is much more effective than magnetic focusing for slow moving particles. This results in a cost savings of a factor of about 100 or more.

The total cost of the prototype is less than \$200,000. It will accelerate Hg^{1+} from .4 MeV to about 1.8 MeV.

In order to provide a beam for the linac, a preaccelerator has been designed and built. It incorporates a number of design innovations. It is the first accelerator to use a Gabor⁽⁵⁾ lens as the focusing element between the ion source and the acceleration gap. The acceleration column itself consists of a single glass tube, resulting in a simple design which is about 20 times less expensive than conventional ceramic columns.

III. BEAM NEUTRALIZATION:

The operation of a 16 MHz buncher allowed the beam to be brought to current densities much higher than would be allowed without some degree of neutralization. However, we were not successful in reaching current densities as high as would have been possible with complete neutralization. Although the results were much cleaner at 16 MHz than previous attempts at 50 MHz, it seems clear that a lower frequency buncher would do better. The next round of experiments will be done at 2 MHz.

REFERENCES

- (1) LLL Laser Program Annual Report - 1976.
- (2) R. Hancox, System Studies of Proposed Fusion Reactors, in Vol. 12 of the Proceedings of the European Nuclear Conference, Paris (April 1975).
- (3) A. W. Maschke, Conceptual Design of a Heavy Ion Fusion Energy Center Report BNL 50817.
- (4) J. T. Keane, Design of Quarter Wavelength Resonator for 2 Megahertz Heavy Ion Linear Accelerator Report BNL 50872.
- (5) R. M. Mobley, Gabor Lenses--Experimental Results at Brookhaven, Proceedings of the Heavy Ion Fusion Workshop at Argonne National Laboratory, Sept. 19-26, 1978.

HEAVY ION FUSION FORMAL REPORTS

<u>TITLE</u>	<u>AUTHOR</u>	<u>BNL#</u>	<u>DATE</u>
Proceedings of the Heavy Ion Fusion Workshop		50769	October 17-21, 77
Conceptual Design of a Heavy Ion Fusion Energy Center	A.W.Maschke	50817	March 13, 1978
Heavy Ion Fusion Overview Symposium on Relativistic Heavy Ion Research GSI DARMSTADT	A.W.Maschke	24377	March 7-10, 1978
Buncher Cavity for 750 keV Protons	J.T.Keane	50824	April 10, 1978
Preliminary Measurements of Plasma Density	J.T.Keane	50825	April 11, 1978
Low Beta Accelerator for Xenon	J.T.Keane	50832	April 3, 1978
20 kW Transmitter for CW Operation at 50 or 17 MHz	J.T.Keane	50833	April 4, 1978
Design of Quarter Wavelength Resonator for 2 Megahertz Heavy Ion Linear Accelerator	J.T.Keane	50872	July 12, 1978

HEAVY ION FUSION TECHNICAL NOTES

<u>NO.</u>	<u>TITLE</u>	<u>AUTHOR</u>	<u>DATE</u>
3.	Optics for the Experimental Low Beta Linac	J-L LeMaire	October 13, 1977
4.	HIBT - Heavy Ion Beam Transport Program	J-L LeMaire	October 25, 1977
5.	Gabor Lens Formulae	A.W. Maschke	March 28, 1978
6.	Ion Beam Transport Program	A. A. Irani	October, 1978
7.	Class C Operation of RCA 7835 Amplifier	J. T. Keane	Nov. 1978
8.	Initial Operating Results of the 2 MHz Amplifier and Quarter Wavelength Resonator	J.T. Keane and R. Sanders	Nov. 1978
9.	Calculation of 2 MHz Linac Parameters	A. W. Maschke	December, 1978

PAPERS SUBMITTED TO HEAVY ION FUSION WORKSHOP--BNL OCTOBER 17-21, 1977. BNL# 50769

TITLE

AUTHORS

Reviews of Current Laboratory Programs

A.W. Maschke

Low Beta Linacs

J.T. Keane, R. Kustom,
A. Moretti, J. Staples,
T. K. Khoe

Saturation of Space Charge Driven Instabilities
in Beam Transport Systems

I. Haber, A.W. Maschke

Estimate of the Longitudinal Self Electric
Field of an Ion Beam

A. A. Irani

Systems Cost

J.T. Keane, P. Grand, G. Danby,
J. Spiro, D. Sutter, F. Cole,
E. Hover, K. Freytag, R. Burke

PROCEEDINGS TO HEAVY ION FUSION WORKSHOP--ARGONNE LABORATORY SEPTEMBER 19-26, 1978

TITLE

BNL#

AUTHORS

Heavy Ion Fusion Development
Plan

25301

A. W. Maschke

Low Beta Linacs

25172

J.T. Keane, R. Adams,
R. Sanders, F. Cole,
A. Faltens, R. Gluckstern,
W. Hermannsfeldt, H. Kim,
R. Stokes, D. Young,
J. Kalbunde, A. Moretti,
J. Staples

Gabor Lenses--Experimental Results
at Brookhaven

25173

R. M. Mobley

Note on Xenon Tests With LBL
Mats Source

25095

R. M. Mobley

Neutralization of Positive Particle
Electron Trapping

23655

R. M. Mobley, A.A. Irani,
A. W. Maschke, J-L LeMaire

Gabor Lens Theory

25023

A. A. Irani

ABSTRACTS SUBMITTED TO 1979 PARTICLE ACCELERATOR CONFERENCE--Oct-Nov.1978
SAN FRANCISCO, CA

<u>TITLE</u>	<u>BNL#</u>	<u>AUTHORS</u>
Low Beta Accelerating System for Heavy Ions	25162	A. Bertsche, J. Brodowski, A. W. Maschke and R. Sanders
Bunched Beam Neutralization	25163	G. M. Gammel, A.W. Maschke, R. M. Mobley
500 kV Mercury Accelerator	25161	J. Brodowski, A.W. Maschke, R. M. Mobley, J.T. Keane, and E. Meier
Gabor Lenses	25024	R. M. Mobley, G. Gammel, A. W. Maschke

SUBMITTED TO 2ND INTERNATIONAL CONFERENCE ON HIGH POWER ELECTRON BEAM RESEARCH
AND TECHNOLOGY OCTOBER 3-4, 1977

<u>TITLE</u>	<u>BNL#</u>	<u>AUTHORS</u>
Space Charge Neutralization of High Brightness Ion Beams	23520	R. M. Mobley, A.A. Irani, J-L LeMaire, A.W. Maschke

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the U.S. nor the U.S. Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or 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.

PRINTED IN THE UNITED STATES OF AMERICA
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price: Domestic \$4.00

Microfiche \$3.00