

GA-A--20111

DE91 002717

A 15 MeV PROTON DIAGNOSTIC FOR DIII-D

by

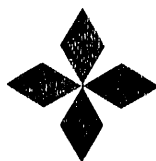
Hau Duong* and W.W. Heidbrink*

*University of California, Irvine

This is a preprint of a paper to be presented at the 8th Topical Conference on High Temperature Plasma Diagnostics, May 7-10, 1990, Hyannis, Massachusetts, and to be printed in the *Proceedings*.

Work supported by
Department of Energy
Contract DE-AC03-89ER51114

GENERAL ATOMICS PROJECT 3466
OCTOBER 1990



GENERAL ATOMICS

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

A 15 MeV proton diagnostic for DIII-D

HAU DUONG AND W.W. HEIDBRINK

University of California, Irvine, California 92717

A 15 MeV proton diagnostic that is patterned after the ASDEX proton probe is presently being fabricated for the DIII-D tokamak. A bellows assembly inserts a silicon detector into the vacuum for plasma operation and retracts it for baking. The detector preamplifier is situated in a reentrant tube (at atmosphere) beside the detector; electrically, the whole assembly is referenced to vessel potential. Orbit calculations in realistic magnetic field geometries predict a proton detection efficiency of $O(10^{-7})$. The diagnostic will be used for burnup studies at high β and particle transport studies in the H-mode.

INTRODUCTION

Charged fusion products have been detected with silicon surface barrier detectors in the PLT,¹⁻⁴ PDX,⁵ TFR,⁶ ASDEX,⁷ TFTR,⁸ and JET⁹ tokamaks. Applications of these measurements have included studies of the confinement of 0.8 MeV ³He ions^{5,10,11} and studies of the transport of thermal ³He ions.^{2,12,13} We have designed and begun fabricating a similar diagnostic for studies of particle transport in the H-mode and of fusion-product confinement at high β in the DIII-D tokamak. This paper describes the mechanical and electrical design of the probe (Section I), the calculated signal levels (Section II), and the anticipated applications (Section III) of this new diagnostic.

I. MECHANICAL AND ELECTRICAL DESIGN

At the center of the 15 MeV proton diagnostic is a rectangular silicon surface barrier detector (SSBD).¹⁴ The SSBD has an active area of 0.3 cm \times 2.5 cm and a maximum depletion depth of 2.0 mm. A reverse bias (380 V maximum) is applied to the p-n junction of the detector, which creates a depleted region in the sensitive portion of the detector. In this depletion region, electron-hole pairs are created for each 3.62 eV of energy deposited by a proton or other charged particle. This results in a current pulse that is proportional to the energy of the incident particle. The depletion depth of 2.0 mm exceeds the range of 15 MeV protons in silicon (1.4 mm).

The detector housing consists mainly of a stainless steel platform and an inconel shield cap (Fig. 1). The shield cap prevents photons from the plasma from striking the detector. Incident protons enter through a slot in the shield cap that is oriented

at a 45° angle (away from the plasma) with respect to the detector's normal. A $\sim 100 \mu\text{m}$ aluminum foil is placed directly on top of the diode to further shield it against scattered photons, other fusion products, and background plasma. A second, "blind", detector of equal active area and depletion depth is placed directly beneath the primary diode to diagnose the background from 14 MeV neutrons, X rays, and other forms of interference. To minimize noise, most ORTEC¹⁴ diodes are designed with the sensitive face of the detector at ground potential. Therefore, the applied bias is supplied to the bottom face of the detector via a copper detector holder that is connected with a flexible wire to a vacuum feedthrough. The detector holder is insulated from the support platform with Macor.

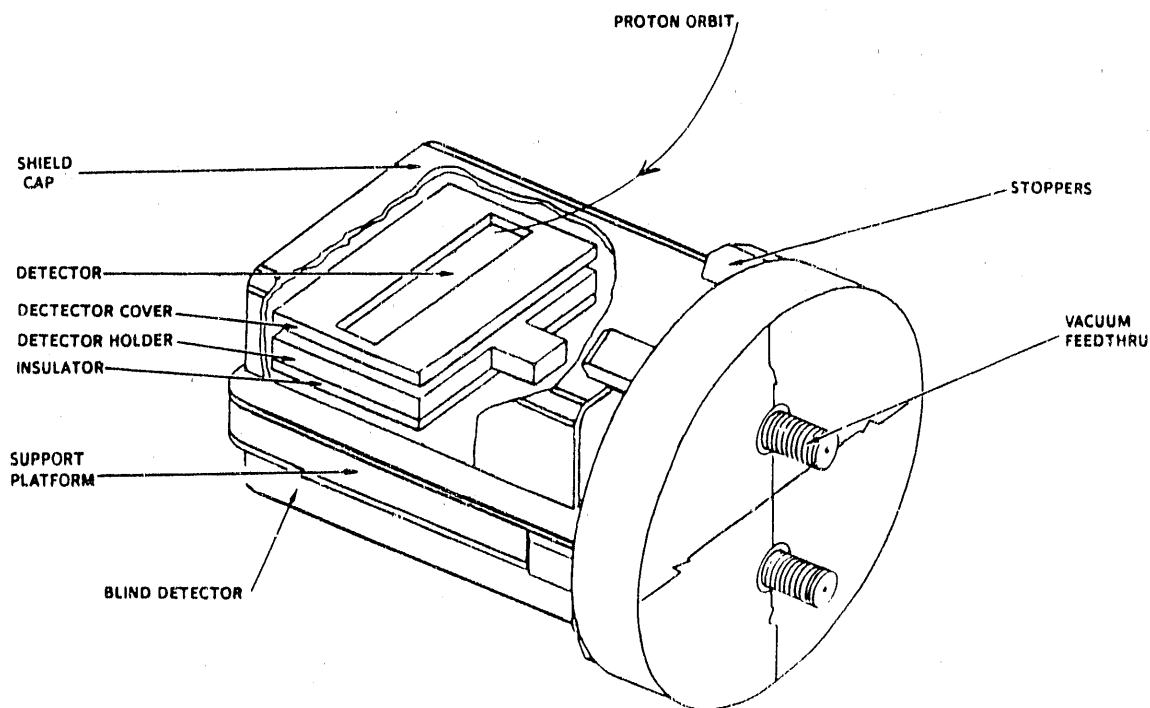


Fig. 1. Cutaway drawing of the detector head assembly. A typical proton orbit into the detector is shown.

The detector assembly (Fig. 1) is attached to the end of the bellows assembly illustrated in Fig. 2. When inserted for plasma operation, the detector is situated near the outer wall of the vacuum vessel ($R = 227$ cm), facing upward, displaced downward from the midplane ($z = -79$ cm) in the direction of the ion ∇B drift (for the normal DIII-D toroidal field orientation). When the vacuum vessel is baked to 300° C, the probe is retracted behind a gate valve to protect the detector. The valve-bellows assembly also allows installation and maintenance of the probe without venting the vessel to atmosphere. During plasma operation, an inconel shield minimizes heating of the detector head. The shield is designed to absorb as much of the plasma radiative heat load as possible without obstructing the proton orbits. Calculations predict a probe temperature reduction of approximately 20% with usage of the shield. The vacuum interface occurs at the end of a reentrant tube near the detector (Fig. 1); the preamplifiers are housed in this tube just outside the vacuum flange (Fig. 2). The inward force on the flange due to atmospheric pressure is approximately 90 N. The tube is prevented from shooting into the vacuum vessel by a series of stops located along the bellows guides and around the probe head. A manual cable and pulley system is used to retract the probe.

The electronics for the diagnostic are illustrated in Fig. 3. The electrical common for the detector, preamplifier, amplifier, and detector bias are allowed to float to the vessel potential in order to minimize charge coupling to the detector via stray capacitances. This electrical configuration was employed by Bosch,⁷ who achieved excellent energy resolution and noise immunity. The preamplifier¹⁵ is a current-sensitive low-input impedance amplifier that converts fast current pulses into

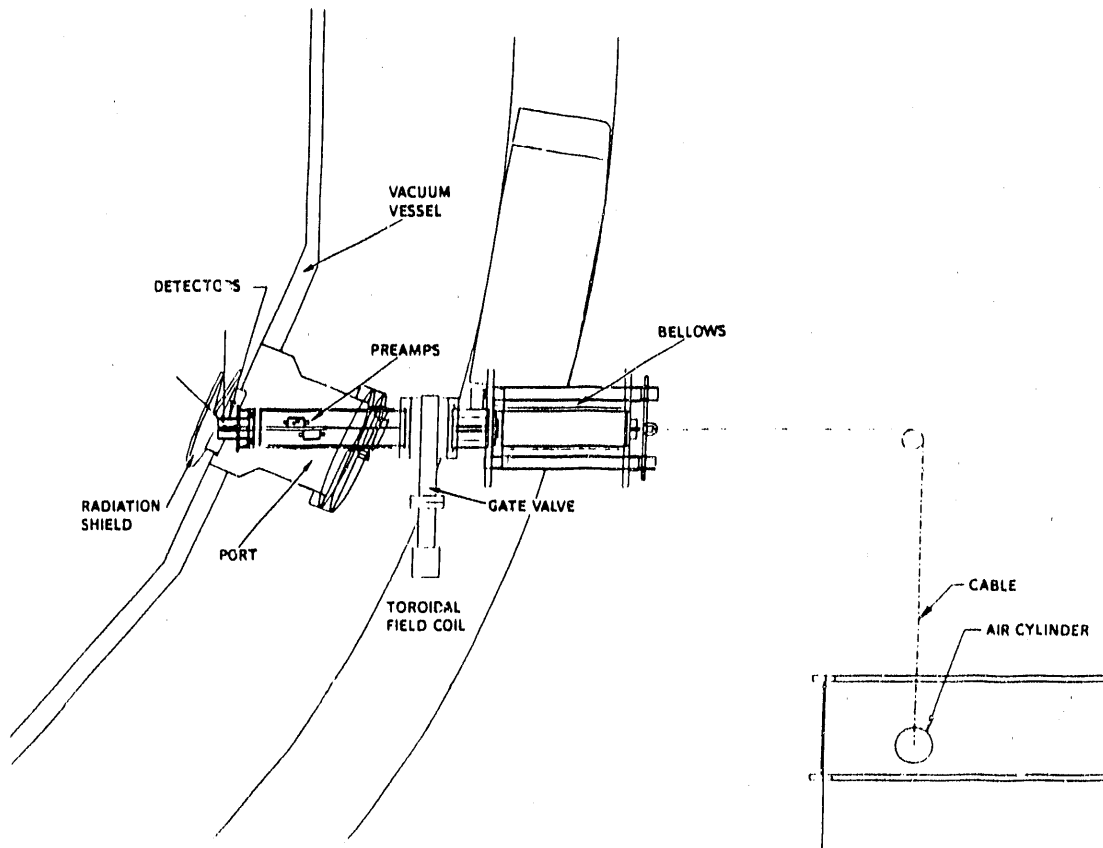


Fig. 2. Elevation of the 15 MeV proton diagnostic.

voltage pulses. Relative to a charge-sensitive preamplifier, a current-sensitive preamplifier offers better temporal response at the expense of energy resolution. Since the expected Doppler width of the 15 MeV proton line is several MeV,¹⁶ energy resolution can be sacrificed in order to avoid difficulties associated with pulse pileup. The amplifier,¹⁷ high voltage supply,¹⁸ and preamplifier power supply are housed in a NIM crate in an electrically isolated rack. The amplified signal passes through an optical isolator¹⁹ to the DIII-D "Annex", where the signal is analyzed by a bank of single

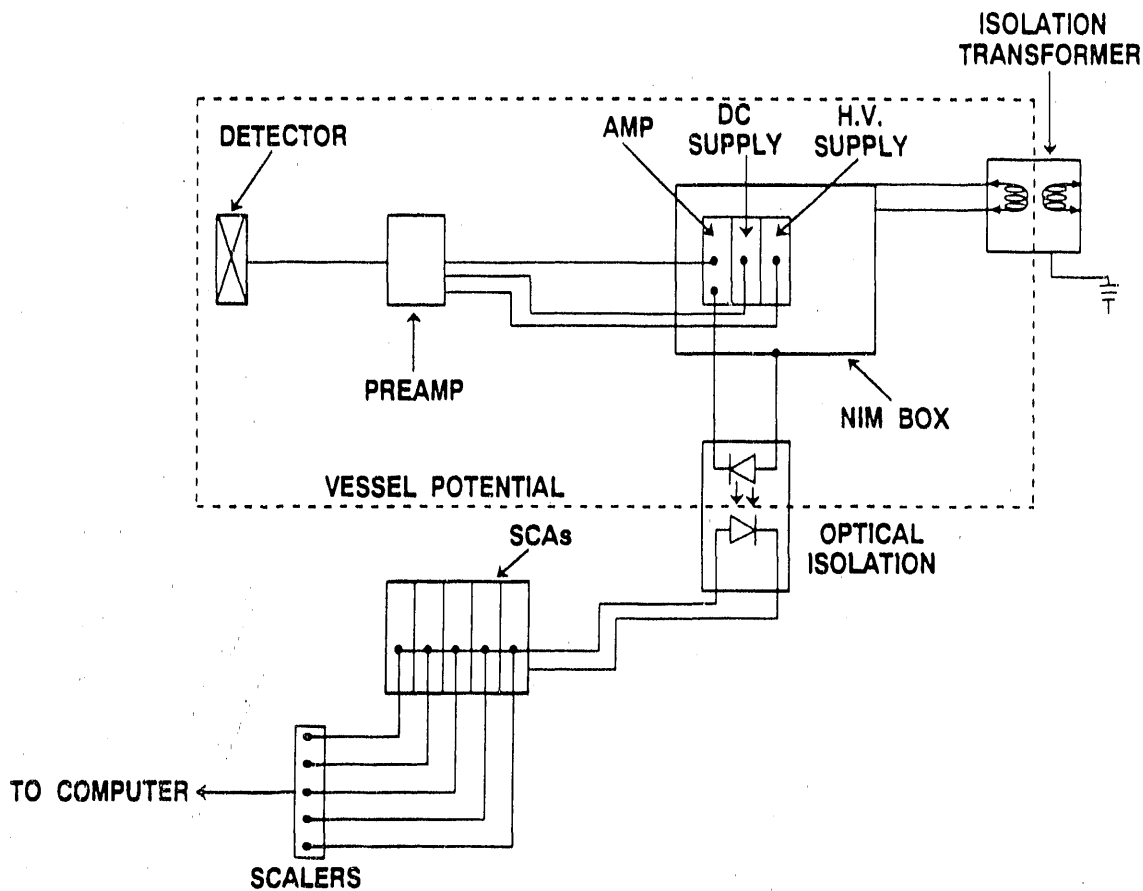


Fig. 3. Block diagram of the electronics for the 15 MeV proton diagnostic. The electronics for the blind detector are identical to those for the proton detector. Signal from the blind diode is subtracted from the proton diode signal during analysis.

channel analyzers²⁰ and scalers.²¹ Archived data are transferred to a VAX cluster²² for analysis.

II. DETECTOR EFFICIENCY

The fraction of created 15 MeV protons that strike the detector, or *detection efficiency* of the probe, is calculated by following the proton orbits from the detector backward in time into the plasma. This is accomplished with the aid of a modified

version of the orbit code developed at Princeton for fusion product studies.²³ The program integrates the equation of motion of a particle of mass m and charge q in an external magnetic field \vec{B} ,

$$\frac{d\vec{v}}{dt} = \frac{q}{m}(\vec{v} \times \vec{B}), \quad (1)$$

to find the orbit path. The original Princeton code assumed circular flux surfaces. DIII-D flux surfaces are asymmetrical and elongated and cannot be accurately modelled analytically. Instead, the magnetic fields were calculated numerically using the EFIT equilibrium code.²⁴ This code uses actual data from edge magnetic diagnostics to reconstruct the plasma shape and current profile. Typical 15 MeV proton orbits for a high β discharge and a high-current, H-mode discharge are illustrated in Fig. 4.

The modified orbit code integrates the equation

$$\epsilon = \frac{\int dA \int \cos \theta d\Omega \int S dl}{4\pi \int S dV}, \quad (2)$$

where ϵ is the detector efficiency, A is the detector area, Ω is the detector solid angle, θ is the angle between the incident proton velocity vector and the detector normal, dV is the plasma volume element, and S is the d - ^3He fusion emissivity. The equation is derived from conservation of phase space by assuming that the volume in phase space intercepted by the detector must equal the intercepted phase space volume of the plasma. Calculation of the detection efficiency with the orbit code results in a value of $\epsilon = 2.4 \times 10^{-7}$ for a typical high β discharge [Fig. 4(a)] and $\epsilon = 1.6 \times 10^{-7}$ for a typical high current discharge [Fig. 4(b)]. Since typical $d(d,n)^3\text{He}$ reaction rates

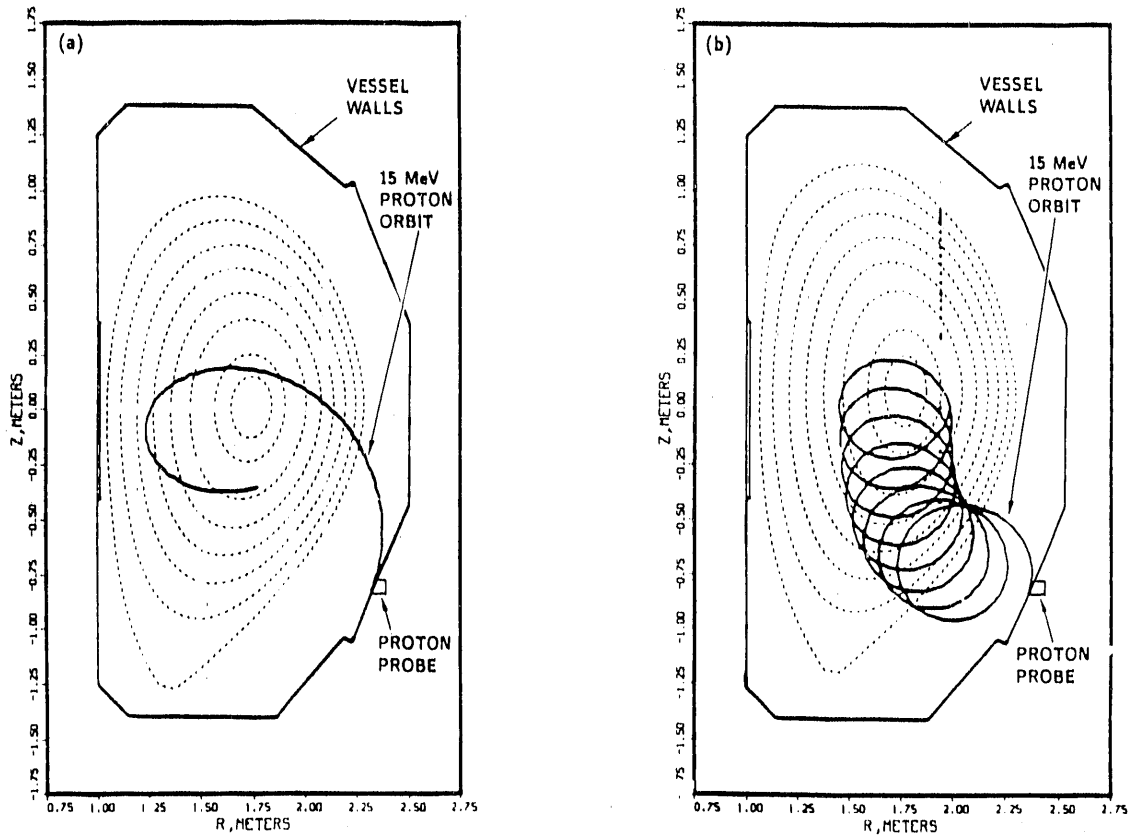


Fig. 4. Poloidal projection of a 15 MeV proton orbit onto the DIII-D cross section. Note that the relatively low toroidal field of DIII-D allows centrally-born protons to strike the detector mounted near the vacuum vessel wall. The dotted lines are the flux surfaces calculated by EFIT.²⁴ (a) $B_t = 0.81$ T; $I_p = 1.28$ MA; $\beta_t \simeq 6\%$. (b) $B_t = 2.13$ T; $I_p = 1.93$ MA.

are 10^{14-15} in DIII-D and the ratio of $d(^3\text{He},p)\alpha$ reactions to $d(d,n)^3\text{He}$ reactions is theoretically of $O(10^{-3})$,⁵ this implies that typical count rates should exceed 10^4 cps. We plan to corroborate our calculated detection efficiencies with ^3He gas puffing experiments similar to those performed on PLT.⁵

III. APPLICATIONS

Development of the 15 MeV proton diagnostic on DIII-D is targeted towards two main experiments. The first of these is a study of the confinement of 0.8 MeV ^3He ions in high β plasmas using the "burnup" technique.⁵ A previous study of fusion-product confinement at high β found large anomalous losses due to the fishbone instability.¹⁰ Since an ignited tokamak must confine alpha particles at high β to be economically attractive, it is important to investigate the generality of this previous study. In DIII-D, we hope to study high β plasmas that are stable to fishbones and to incorporate simultaneous measurements of the time evolution of the 1 MeV triton burnup.

A second planned study is to compare particle transport of ^3He ions in the L-mode, the quiescent H-mode, and at ELMs. Previously, the confinement of trace high Z impurity ions was found to improve at the L-to-H transition.²⁵ We also hope to study deuterium particle transport during ^3He neutral beam injection into a hydrogen or helium H-mode plasma.

ACKNOWLEDGMENTS

We thank G. Thurston, R. Gallix, and S. Visser for their assistance in designing the proton probe and R. Fisher, L. Lao, J. McChesney, and J. Kim for helpful discussions. The work was supported by General Atomics subcontract SC120531 under U.S. DOE Contract DE-AC03-89ER51114.

REFERENCES

- ¹ R. E. Chrien *et al.*, Phys. Rev. Lett. **46**, 535 (1981); R. E. Chrien and J. D. Strachan, Phys. Fluids **26**, 1953 (1983).
- ² R. E. Chrien, H. P. Eubank, D. M. Meade, and J. D. Strachan, Nucl. Fusion **21**, 1661 (1981).
- ³ W. W. Heidbrink and J. D. Strachan, Rev. Sci. Instrum. **56**, 501 (1985).
- ⁴ W. W. Heidbrink, Nucl. Fusion **24**, 636 (1984).
- ⁵ W. W. Heidbrink, R. E. Chrien, and J. D. Strachan, Nucl. Fusion **23**, 917 (1983).
- ⁶ G. Martin, Ph.D. Thesis.
- ⁷ H.-S. Bosch, Diagnostik geladener Fusionsreaktionsprodukte in ASDEX, Max-Planck-Institut für Plasmaphysik IPP III/116 (1987).
- ⁸ J. D. Strachan, Rev. Sci. Instrum. **57**, 1771 (1986).
- ⁹ P. Van Belle, J. Gowman, M. Hone, N. Jarvis, V. Merlo, G. Sadler, "Measurements of 14.7 MeV Proton Emission from the JET Plasma," JET-IR(86)04, p. 75 (1986).
- ¹⁰ W. W. Heidbrink, Ralph Hay, and J. D. Strachan, Phys. Rev. Lett. **53**, 1905 (1984).
- ¹¹ J. D. Strachan, Nucl. Fusion **29**, 163 (1989).
- ¹² R. Budny *et al.*, J. Nucl. Materials **121**, 294 (1984).
- ¹³ J. D. Strachan and A. Chan, Nucl. Fusion **27**, 1025 (1987).

- 14 EG&G ORTEC, Oak Ridge, TN.
- 15 ORTEC VT120.
- 16 W. W. Heidbrink, Nucl. Instrum. Meth. **A248**, 499 (1986).
- 17 Canberra DDL 1411A, Meriden, CT.
- 18 ORTEC 459.
- 19 Dymec 5710, Winchester, MA.
- 20 ORTEC 550A.
- 21 LeCroy 8590, Chestnut Ridge, NY.
- 22 Digital Equipment Corporation.
- 23 W. W. Heidbrink, "Tokamak Diagnostics using Fusion Products," Ph.D. Thesis, Princeton University (1984).
- 24 L. Lao *et al.*, Nucl. Fusion **25** (1985) 1611.
- 25 M. E. Perry, N. Brooks, D. Content, R. Hulse, M. Ali Mahdavi, and H. W. Moos, "Impurity Transport During DIII-D H-Mode," GA-A19286 (1989).

END

DATE FILMED

12 / 03 / 90

