RECEIVED
APR 17 2000
OSTI

FINAL TECHNICAL REPORT

DE-FG02-94ER54286

SUPPORT OF HAMPTON UNIVERSITY CENTER FOR FUSION RESEARCH AND TRAINING

JULY 1 1999

We have no objection from a patent
standpoint to the publication or
dissemination of this material.

MP Dvorak 4-12-00
Office of Intellectual Date
Property Counsel
DOE Field Office, Chicago

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, make 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.

CONTENTS

RESEARCH

PROJECT I Heat Deposition on Divertor Plate using Maps

- 1. Progress Made.....44-48
- 2. References.....50-51

PROJECT II Anomalous Transport in Toroidal Plasmas

- 1. Progress Made.....59-61
- 2. References.....63

- Publications, Contributed Papers and
Invited Seminars.....64-69

EDUCATION, TRAINING, OUTREACH AND PUBLIC AWARENESS

- 1. Introduction.....7-10
- 2. Accomplishments.....11-28
- 3. Documentation

PROGRESS MADE

We have investigated the single-null divertor tokamaks using the Simple Map and the Symmetric Simple Map. We have investigated the effects of low m perturbations using the Low MN Map. We have investigated the effects of external current carrying coils using the Dipole Map. We have modelled the shear near edge in single-null divertor tokamaks using the Adjustable Shear Map. We have investigated the effects of aperiodic time dependent perturbations using the Standard Map with Aperiodic Iteration Dependent Term. Here we give a brief summary of all this work in last three years.

Single-null Divertor Tokamak using the Simple Map /1-3,14,15/

Faculty:	Verma, Punjabi, Calvin and Boozer
Graduate Student:	Mr. Terry Smith
High School Students:	Ms. Tiffany Fisher, Ms. Tiffani Braswell

For the Simple Map, the shape of the magnetic surfaces varies with toroidal angle. The width w of the stochastic layer increases very rapidly with k , while the edge safety factor q_{edge} falls sharply with k . An appropriate combination of k and N_{map} will represent a tokamak with a given width w and a given q_{edge} . N_{map} is the number of iterations of the Simple Map which is equivalent to a single toroidal circuit of the tokamak.

Using the continuous analog of the Simple Map, we can follow the field lines to calculate their footprint on the divertor plate. These footprints are helical stripes and have the same structure and shape for different values of k . The area of the footprint increases very rapidly with k . The fraction of magnetic flux diverted onto the plate remains roughly constant at about 0.18 for small k , and increases to about 0.28 as k increases. Increasing the width of the stochastic layer results in a monotonic increase in the area of the stochastic layer as well as in the area of the footprint. However, the size of the footprint increases faster than that of the stochastic layer. As the width increases from about 1% to 10% of the distance from the O-point to the X-point, the time integrated average heat flux density on the plate decreases monotonically by about a factor of 1/3. The poloidal and toroidal strike angles and strike lengths have a self-similar structure. The larger of the Liapunov exponents for the chaotic field lines shows self-similar

structure and discontinuities for open field lines.

Single-null Divertor Tokamak using the Symmetric Simple Map /4-16/

Faculty:	Ali, Punjabi, Calvin and Boozer
Graduate Student:	Mr. Michael Watson
Undergraduate Student:	Ms. Chaka Meyer, Ms. Joni Burton
High School Student:	Ms. Michelle Deal, Mr. Alphonso Basemore

The Simple Map followed by its reverse with the map parameter $k \rightarrow -k$ results in the Symmetric Simple Map given by

$$y_{n+1} = y_n + 2k x_n - 2k^2 y_n (1 - y_n)$$

$$x_{n+1} = x_n - k y_n (1 - y_n) - k y_{n+1} (1 - y_{n+1})$$

The Symmetric Simple Map is a better representation of the magnetic geometry of single-null divertor tokamaks. The good surfaces of this map at arbitrary toroidal locations have a higher degree of axisymmetry when compared with the good surfaces of the Simple Map, and the good surfaces in the principal plane are symmetric about the y axis.

We fix the edge safety factor, q_{edge} , for a single-null divertor tokamak with a stochastic scrape-off layer at the value of about 3, and increase the width of the stochastic scrape-off layer near the X-point from about 2% of the minor radius to about 15%. We find that: (1) The toroidal magnetic flux contained in the stochastic layer increases by about a factor of seven. (2) The area of the footprint of field lines on the plate increases by about an order of magnitude. (3) The fraction of toroidal flux diverted onto the plate from the stochastic layer increases by about one-third. (4) (1) through (3) imply that the magnetic flux density striking the plate remains roughly constant. (5) The average number of toroidal circuits made before the field lines strike the plate normalized by the number of toroidal circuits required to keep $q_{\text{edge}} = 3$ decreases by about a factor of 3.5. (6) The average number of poloidal circuits made before the field lines strike the plate decreases by a factor of 3. (7) (4) through (6) imply that although the flux density on the plate may remain roughly constant, the rate at which the heat flux strikes the plate may increase by an order of magnitude.

Effects of Low mn Perturbation using the Low MN Map /17-22/

Faculty: Verma, Punjabi and Boozer
Graduate Student: Mr. Terry Smith
High School Student: Ms. Tiffani Braswell

The Simple Map with low MN perturbation is given by

$$x_{n+1} = x_n - k y_n \left(1 - y_n - \delta \cos \frac{2\pi (n+1)}{N_{map}} \right)$$

$$y_{n+1} = y_n + k x_{n+1} \left(1 + \delta \cos \frac{2\pi (n+1)}{N_{map}} \right)$$

We call this the Low MN Map. We use the Low MN map to investigate the effects of low MN perturbations on the chaotic field line trajectories and their footprint on the collector plate in single-null divertor tokamaks.

(1) The width of the stochastic layer increases rapidly with δ . For $\delta=0$, the width is about 0.3% of the minor radius when $k=0.6$. (2) The edge safety factor q_{edge} remains roughly constant for $\delta=0$ to 10^{-5} . q_{edge} falls sharply for $\delta=10^{-5}$ to 10^{-4} . For higher values of δ , q_{edge} fluctuates wildly. A change in the topology of the footprint occurs when δ increases beyond 10^{-10} . (3) After this change the helical stripes join up to make arcs. The area of the footprint remains almost constant from $\delta=0$ to 10^{-5} , and then it increases rapidly as δ is increased. (4) $f(\delta)$ denotes the fraction of the toroidal flux from the stochastic layer which ends up on the divertor plate. When $\delta=0$, $f=0.18$. As δ increases from 10^{-9} to 10^{-5} , f is suddenly reduced to 0.026 and stays roughly constant. On further increase of δ , it roughly reattains the value it had in the absence of perturbation. (5) The toroidal and poloidal strike angles and field line length, ϕ_{strike} , θ_{strike} and l_{strike} , show self-similar structure. (6) There is a slight increase in the average values, $\langle \phi_{strike} \rangle$, $\langle \theta_{strike} \rangle$ and $\langle l_{strike} \rangle$, before they strike the divertor plate as δ increases from 10^{-9} to 10^{-5} . Then as δ is increased up to 10^{-2} , there is a sharp drop in the average values. (7) There is a sharp increase in the median values of ϕ_{strike} , θ_{strike} and l_{strike} before they strike the divertor plates as δ increases from 10^{-6} to 10^{-5} . As δ increases to 10^{-4} , there is a sharp drop in median values of ϕ_{strike} , θ_{strike} and l_{strike} . (8) The larger of the two Liapunov exponents for the Low MN Map in the chaotic region shows a clear change in pattern as δ increases above 10^{-5} . In the region of good surfaces it shows large discontinuities.

Effects of External Current Carrying Coil using the Dipole Map /23-31/

Faculty: Ali, Punjabi and Boozer
Graduate Student: Mr. Michael Watson
Undergraduate Student: Ms. Joni Burton
High School Student: Mr. Alphonso Basemore, Ms. Michelle Deal

To investigate the effects of external magnetic coils on the heat deposition on the plate, Prof. Allen Boozer of Columbia University has developed a map called the Dipole Map. The Dipole Map represents the effects of a magnetic perturbation produced by a dipole field. The map is applied at the end of each N_p^{th} iteration of the Symmetric Simple Map. For a dipole located at $x=0, y=y_s$ at a distance s from the separatrix in the lower half plane, the effect of dipole perturbation can be represented by the implicit map

$$x_n = x_{n+1} + F(x_{n+1})$$

$$y_{n+1} = y_n + \delta s^3 \frac{(y_n - y_s + s)^2 - x_{n+1}^2}{[x_{n+1}^2 + (y_n - y_s + s)^2]^2}$$

where

$$F(x_{n+1}) = -2\delta x_{n+1} (y_n - y_s + s) \frac{s^3}{[x_{n+1}^2 + (y_n - y_s + s)^2]^2}$$

and δ is the normalized perturbation in the magnetic field. The unperturbed magnetic topology is represented by the Symmetric Simple Map.

We have investigated the effect of Dipole Map on the Symmetric Simple Map as the amplitude δ of the dipole perturbation and the distance s of the dipole coil from the last good surface are varied.

We keep the dipole coil fixed at some distance s from the last good surface in the lower half plane. We increase the strength δ of the dipole perturbation smoothly. At some critical value of δ , we observe a large and discontinuous increase in the width of the stochastic scrape-off layer. The increase in the width is larger than an order of magnitude. This is due to the joining together of two regions of spatially intermittent chaos when the dipole strength is increased above the critical value. This is interesting because we can study the case where feedback circuits and currents in dipole coils are used in combination to dynamically control the width of stochastic layer. The width can be altered smoothly or discontinuously. For example, suppose the impurity content of core plasma becomes

intolerable. The diagnostics can detect this. Diagnostics can signal the feedback loop to increase the current in the dipole coil above the critical value. This will cause impurities to be swept into the edge region. Then the dipole current can be reduced below the critical value. A repetition of this process can transport impurities into the scrape-off layer rapidly. This can help to reduce the impurity levels in the core to acceptable values, and help to make the divertor radiative.

Edge Shear using the Adjustable Shear Map /32-34/

Faculty	Lam, Calvin, Punjabi, Boozer
Undergraduate Student:	Mr. Franklin Jones
High School Student:	Mr. Michelangelo Whitten, Mr. C Long

We have done some preliminary work on the Adjustable Shear Map /12, 13, 15/. Recently we have discovered that it may be possible to use the Adjustable Shear map to model negative central shear, an important magnetic configuration for enhanced confinement in tokamaks.

Effects of Aperiodic Time Dependent Perturbation using the Standard Map /35-37/

Faculty:	Ali, Punjabi, Boozer
Graduate Student:	Mr. Richard Truesdale
High School Student:	Mr. Bernard McClendon

We have recently begun exploring the Standard Map with aperiodic iteration-number dependent perturbation to study Arnold diffusion in the stochastic layer.

REFERENCES

* Graduate Student

** Undergraduate Student

*** High School Student

1. Punjabi A., Verma A. and Boozer A., *Phys. Rev. Lett.* **69**, 3322 (1992)
2. Punjabi A., Verma A. and Boozer A., *J Plasma Phys*, **52**, 91 (1994)
3. Punjabi A., Verma A. and Boozer A., *J Plasma Phys*, **58**, 569 (1996)
4. Punjabi A., Ali H and Boozer A., *Phys Plasmas*, **4**, 337 (1997)
5. Chatalov G., *Proceedings of the XII International Conference on Plasma Physics and Controlled Nuc. Fus. Res.*, Nice, France, 12-19 Oct. , **3**, p. 261- 272 (1988)
6. Boozer A. and Rechester A., *Phys. Fluids*, **21**, 682 (1978)
7. Boozer A., *Phys. Fluids*, **26**, 1288 (1983)
8. Cary J. R. and Littlejohn R. G., *Ann. Phys.*, New York, **151**, 1 (1983)
9. Lichtenberg A. J. and Liberman M. A., *Regular and Stochastic Motion*, Springer-Verlag, New York, 1983
10. Pomphrey N. and Reiman A., *Phys. Fluids B*, **4**, 938 (1992)
11. Martin T. J. and Taylor J. B., *Plasma Phys. Contr. Fus.*, **28**, 321 (1984)
12. Punjabi A., Boozer A., Lam M., Kim M. and Burke K., *J. Plasma Phys.*, **44**, 405 (1990)
13. Boozer A. and Pateravic G., *Phys. Fluids*, **24**, 851 (1981)
14. Verma A, Punjabi A and Boozer A, 1996 *International Sherwood Fusion Theory Conference*, **2C30**
15. Fisher T***, Verma A and Punjabi A, *Bull Am Phys Soc*, **41**, 1452 (1996)
16. Ali H, Watson M*, Meyer C**, Punjabi A and Boozer A, *Bull Am Phys Soc*, **40**, 1855 (1995)
17. Verma A, Punjabi A and Boozer A, 1995 *International Sherwood Fusion Theory Conference*, **1D16**
18. Verma A, Smith T*, Braswell T***, Punjabi A and Boozer A, *Bull Am Phys Soc*, **40**, 1884 (1995)
19. Verma A, Smith T*, Punjabi A and Boozer A, *Bull Am Phys Soc*, **41**, 1484 (1996)
20. Verma A, Smith T*, Punjabi A and Boozer A, 1997 *International Sherwood Theory Conference*, **3C44**
21. Verma A, Punjabi A and Boozer A, To be presented at the 39th Annual Meeting, 1997 APS DPP, Pittsburgh, PA
22. Smith T*, *HU Applied Mathematics MS Thesis*, June 1997
23. Ali H, Punjabi A and Boozer A, *Bull Am Phy Soc*, **39**, 1713 (1994)
24. Ali H, Punjabi A and Boozer A, *Bull Am Phys Soc*, **40**, 1884 (1995)
25. Ali H, Watson M*, Punjabi A and Boozer A, 1996 *International Sherwood Fusion Theory Conference*, **1C20** (1996)
26. Basemore A***, Ali H, Watson M* and Punjabi A, *Bull Am Phys Soc*, **41**, 1452 (1996)
27. Burton J**, Ali H and Punjabi A, *Bull Am Phys Soc*, **41**, 1452 (1996)
28. Ali H, Watson M*, Punjabi A and Boozer A, *Bull Am Phys Soc*, **41**, 1484 (1996)

29. Burton J**, Ali H and Punjabi A
1997 Council on Undergraduate Research Capitol Hill Poster Session, April 10
1997 NAFEO High Tech Expo, Washington D. C., April 12
1997 VA/MD/DC American Mathematics Association Regional Conference, April 19
30. Deal M***, Ali H and Punjabi A, To be presented at the 39th Annual Meeting,
1997 APS DPP, Pittsburgh, PA
31. Watson M*, *HU Physics PhD Thesis*, under preparation
32. Whitten M***, Lam M and Punjabi A, *Bull Am Phys Soc*, **41**, 1452 (1996)
33. Jones F**, Calvin M, 1997 VA/MD/DC American Mathematics Association Regional
Conference
34. Long C***, Lam M and Punjabi A, To be presented at the 39th Annual Meeting,
1997 APS DPP, Pittsburgh, PA
35. Ali H, Truesdale R*, Punjabi A and Boozer A, *1997 International Sherwood Theory
Conference*, **3C43**
36. Truesdale R*, *HU Applied Mathematics MS Thesis*, June 1997
37. McClendon B*** and Punjabi A, To be presented at the 39th Annual Meeting,
1997 APS DPP, Pittsburgh, PA

PROGRESS MADE

We have employed our Monte Carlo method for transport due to MHD modes to investigate the trajectories of suprathermal alpha particles in the rippled field of TFTR and electron transport in the chaotic magnetic fields in the edge of the reversed field pinch ZT40M. We have also investigated the problem of edge plasma transport in DIII-D using catastrophe theory. Here we summarize the progress made from September 1994 to August 1997.

Trajectories of Suprathermal Alpha Particles in the Rippled Field of TFTR /12-15/

Faculty: Punjabi, Lam and Boozer
Undergraduate Student: Ms. Melissa Davis

We have applied our Monte Carlo Method to study the transport of suprathermal alpha particles in the rippled field of the TFTR. We take the transport mechanism to be the spatial variation of magnetic field strength $B(\chi, \theta, \phi)$ on the good magnetic surfaces /11/. We employ the drift Hamiltonian equations of motion in practical, noncanonical, rectangular Boozer coordinates /11/. For equilibrium fields and currents, we use the code SHAF.F from Professor Roscoe White of PPPL /12/. The field strength B is given by $B = B_0 + B_1$, where $B_0 = \sum b_l P_l(x, y)$ with $x = \chi^{1/2} \cos(2\pi\theta)$ and $y = \chi^{1/2} \sin(2\pi\theta)$. Note that angles change by unity in one circuit. The polynomial $P_l(x, y) = 1, x, x^2, \dots, xy^4$. Perturbation in B due to ripple in TFTR is represented by

$$B_1 = d_0 e^{\frac{\sqrt{(x-x_r)^2 + by^2}}{\omega}} \sin(2\pi N\phi)$$

where x_r is the ripple center, b is ellipticity of ripple, ω is the ripple scale length, N is the number of toroidal coils. In SHAF.F, B_1 is approximated by $\exp\{\sum P_l(x, y)\} \sin(2\pi N\phi)$. We have chosen the alpha source profile $-(1-r^2)^9$ and the birth energy of alphas is chosen to be $E_{0\alpha} = 3.51$ MeV. The effects of pitch angle scattering and energy scattering of alphas due to collisions with electrons, deuterons, tritons and Carbon-12 impurities are also included. The

collision frequencies are determined from: deflection frequency $\nu_d^a = \sum \frac{1}{2} \nu_{\perp}^{a/\beta}$, energy

scattering frequency $\nu_E^a = \sum \frac{m}{m_{\beta}} \psi(x^{a/\beta}) \nu_0^{a/\beta}$ with $\beta = e, D, T$ and C^{12} . The carbon 12

density is determined from $n_c = \left(\frac{Z_{eff} - 1}{30} \right) n_e$. The deuteron and triton densities are given

from $n_d = n_T = \left(\frac{6}{5} - \frac{Z_{eff}}{5} \right) \frac{n_e}{2}$. Profiles for n_e, T_e, T_D, T_T, T_c are taken from experimental

data for TFTR shot # 67885 provided by Professors Bundy and Steward Zweben of PPPL. The other parameters for this shot used in the calculations are $R_{minor} = 84.3$ cms, $R_{major} = 281.0$ cms, $B_0 = 4.5564$ kG, $q_0 = 0.8$, $q_a = 2.71$ and $Z_{eff} = 2.8355$.

Dr. Maria Lam has worked on this problem only during the summers of 1995 through 1997. Punjabi and Lam have developed the code CRAYALPHA32.F. This code has now been fully developed, debugged and tested on the Hampton University Computer Science Department CRAY EL92 minisupercomputer. The code integrates the drift trajectories of alphas in the rippled field of TFTR from time $t=0$ to $t=0.75$ sec (unless the particle strikes the wall before that time). The code calculates the particle diffusion coefficient, the energy transferred from alphas to electrons, deuterons, tritons and carbon 12 as a function of minor radius, the strike position, and other related parameters. Results have been periodically reported at Sherwood Fusion Theory Meetings and APS DPP annual meetings /13-15/.

We plan to make production runs on the newly acquired CRAY EL98 in the HU Computer Science Department. This is a computationally heavy-duty problem. We are hoping that we will get enough time on the new CRAY EL98.

Electron Transport in the Stochastic Fields of Reversed Field Pinch ZT40M /16/

Faculty: Punjabi
Graduate Student: Ms. Myung-Hee Kim

We have also applied our Monte Carlo method to investigate electron transport in the stochastic magnetic fields in the edge region of the Reversed Field Pinch ZT40M. This was the thesis problem for Ms. Myung-Hee Kim for her MS degree in Applied Mathematics. For this problem, the transport mechanism is the loss of magnetic surfaces due to resonant modes

in the edge of ZT40M. The equilibrium magnetic fields are represented by a Bessel function model for RFP. The electron diffusion coefficient D_e is calculated as a function of the amplitude a of the tearing modes. We find three regimes: the Rechester-Rosenbluth regime where D_e scales as a^2 , the anomalous regime where D_e scales faster than a^2 , and the Mynick-Krommes regime where D_e scales slower than a^2 . Inclusion of loop voltage does not affect these results. We are the first to computationally observe the Mynick-Krommes scaling from the saturation of field topology. These results are reported in /16/.

Edge Plasma Transport in DIII-D /17/

Faculty: Punjabi
Graduate Student: Mr. Min Soe

We constructed the advanced two chamber model to investigate the plasma transport in divertor tokamaks. This model includes the effects of charge exchange and radiative losses. We observe that the equilibrium surfaces show topological bifurcations as the electron density in the divertor chamber (normalized by the electron density in the main plasma scrape-off layer) exceeds a critical value. The qualitative features of these bifurcations are in agreement with the experimental observations of the L to H mode transition and the Partially Detached Divertor (PDD) mode in divertor tokamaks. Parameters of the DIII-D tokamak were used in this work. These results are reported in /17/. This investigation was the thesis problem for Mr. Min Soe for his MS degree in Applied Mathematics.

Magnetic Quasi-surfaces /18-19/

Faculty: Punjabi and Boozer

To study anomalous transport due to breakup of the magnetic surfaces, we have developed another technique called magnetic quasi-surfaces /18/. Resistive instabilities contribute greatly to anomalous transport. It is important to separate transport caused by magnetic field line diffusion from particle diffusion. The breakup of magnetic surfaces is suspected to be responsible for significant energy and particle loss. We want to examine field versus particle diffusion at the onset and growth of stochasticity. We have just begun developing and testing codes which marry this approach of magnetic quasi-surfaces to our Monte Carlo /19/.

REFERENCES

* Graduate Student

** Undergraduate Student

1. Kadomtsev, B. B., *Sov. J. Plasma Phys.* **1**, 389 (1975)
2. Kadomtsev, B. B. and Pogutse, O. P., *Sixth Eur. Conf. on Contr. Fus. and Plasma Phys.*, **1**, p 59 (1973)
3. Wesson, J. A., Basic Physical Processes of Toroidal Fusion Plasmas (Proceedings of workshop at Varenna, Italy, 1985) edited by Lampis, G. P. et al, Euratum, Brussels, **2**, p 569 (1986)
4. Pare, V. K. et al, op. cit., p 577
5. Kovrizhnykh, L. M., *Nuc. Fus.*, **24**, 851 (1984)
6. Cary, J. R. and Kotschenreuther, M., *Phys. Fluids*, **28**, 1392 (1985)
7. Liewer, P. C., *Nuc. Fus.*, **25**, 543 (1985)
8. Boozer, A. H., *Phys. Fluids*, **25**, 520 (1982)
9. Boozer, A. H. and Petravic, G. K., *Phys. Fluids*, **24**, 851 (1981)
10. Boozer, A. H., *1987 International Sherwood Fusion Theory Conference*, **2C28**
11. Punjabi A, Boozer A, Lam M, Kim M & Burke K *J Plasma Phys*, **44**, 405-430 (1990)
12. White R B & Boozer A, *PPPL Report no. 3094* (1995)
13. Lam M, Punjabi A and Boozer A, *Bull Am Phys Soc*, **40**, 1649 (1995)
14. Punjabi A, Lam M and Boozer A, *1996 International Sherwood Fusion Theory Conference*, **3C07**
15. Punjabi A, Lam M and Boozer A, *Bull Am Phys Soc*, **41**, 1394 (1996)
16. Kim M* and Punjabi A, *J Plasma Phys*, **56**, 3-12 (1996)
17. Punjabi A and Soe M*, *J Plasma Phys*, **52**, 457-463 (1994)
18. Calvin M and Punjabi A, *Bull Am Phys Soc*, **41**, 1394 (1996)
19. Jones F**, Calvin M, 1996 VA/MD/DC Mathematics Association of America - Regional Conference
20. Boozer A, *Phys. Plasma* **4**, 2962 (1997)

C. Publications, Contributed Papers and Invited Seminars

- * Graduate Student
- ** Undergraduate Student
- *** High School Student

Refereed Publications:

1. Tokamak Divertor Maps, Punjabi A
Verma A and Boozer A
J Plasma Phys, **52**, 91-111 (1994)
2. Bifurcations in an Advanced Two-chamber Model for the Edge Plasma in a Divertor Tokamak
Punjabi A and Soe M
J Plasma Phys, **52**, 457-463 (1994)
3. Electron Transport in the Stochastic Fields of the Reversed-Field Pinch
Kim M and Punjabi A
J Plasma Phys, **56**, 3-12 (1996)
4. The Simple Map for Single-null Divertor Tokamak
Punjabi A, Verma A and Boozer A
J Plasma Phys, **58**, 569-604 (1996)
5. The Symmetric Simple Map for a Single-null Divertor Tokamak
Punjabi A, Ali H and Boozer A
Phys Plasmas **4**, 337-346 (1997)

Papers under preparation:

1. Effects of Low MN Perturbations in Single-null Divertor Tokamaks using Maps I: Constant Width
Verma A, Punjabi A and Boozer A
2. Effects of Low MN Perturbations in Single-null Divertor Tokamaks using Maps II: Variable Width
Verma A, Smith T*, Punjabi A and Boozer A
3. Dipole Map for Single-null Divertor Tokamaks
Ali H, Watson M*, Burton J**, Punjabi A and Boozer A
4. Effects of Aperiodic Time-dependent Perturbations in Divertor Tokamak using Standard Map

Ali H, Truesdale R*, Punjabi A and Boozer A

5. Trajectories of Superthermal Alpha Particles in Rippled Field of TFTR
Punjabi A, Lam M, Davis M** and Boozer A
6. Correlation between Particle Diffusion and Field Diffusion in the Stochastic Fields of Tokamak using Magnetic Quasi-surfaces
Punjabi A and Boozer A

Contributed Papers:

1. Effect of High MN Perturbations on Heat Deposition Pattern on Divertor Plates using Maps
Ali H, Punjabi A and Boozer A
Bull Am Phy Soc, **39**, 1713 (1994)
2. Effect of Low MN Perturbations on Footprints of Field Lines on the Divertor Plates in Single-null Divertor Tokamak
Verma A, Punjabi A and Boozer A
1995 International Sherwood Fusion Theory Conference, **1D16** (1995)
3. Ripple Transport of Suprathermal Alpha Particles in Tokamak
Lam M, Punjabi A and Boozer A
Bull Am Phys Soc, **40**, 1649 (1995)
4. Drift Kinetic Model of Alpha Particle Interaction with a Prescribed Wave
Marable W
Bull Am Phys Soc, **40**, 1682 (1995)
5. Symmetric Simple Map for Single-null Divertor Maps
Ali H, Watson M*, Meyer C**, Punjabi A and Boozer A
Bull Am Phys Soc, **40**, 1855 (1995)
6. Simple Map with Low MN Perturbations for a Single-null Divertor Tokamak
Verma A, Smith T*, Braswell T***, Punjabi A and Boozer A
Bull Am Phys Soc, **40**, 1884 (1995)
7. Symmetric Simple Map with Dipole Perturbations for a Single-null Divertor Tokamak
Ali H, Punjabi A and Boozer A
Bull Am Phys Soc, **40**, 1884 (1995)
8. Educational and Outreach Programs at the HU Center for Fusion Research and Training

Huggins V and Punjabi A
Bull Am Phys Soc, **40**, 8S (1995)

9. Catastrophe in the Stochastic Layer due to Dipole Perturbation
Ali H, Watson M*, Punjabi A and Boozer A
1996 International Sherwood Fusion Theory Conference, **1C20** (1996)
10. Simple Map for Single-null Divertor Map
Verma A, Punjabi A and Boozer A
1996 International Sherwood Fusion Theory Conference, **2C30** (1996)
11. Monte Carlo Simulation of Suprathermal Alpha Particles in Rippled Field of Tokamak
Punjabi A, Lam M and Boozer A
1996 International Sherwood Fusion Theory Conference, **3C07** (1996)
12. Monte Carlo Calculations of Suprathermal Alpha Particles Trajectories in the Rippled Field of TFTR
Punjabi A, Lam M and Boozer A
Bull Am Phys Soc, **41**, 1394 (1996)
13. Correlation Between the Field Line and Particle Diffusion Coefficients in the Stochastic Fields of a Tokamak
Calvin M and Punjabi A
Bull Am Phys Soc, **41**, 1394 (1996)
14. Web Presentation to Raise Awareness of High School Students about Fusion Science
Hicks J*** and Calvin M
Bull Am Phys Soc, **41**, 1451 (1996)
15. High Adjustable Shear Map for a Single-null Divertor Tokamak
Whitten M***, Lam M and Punjabi A
Bull Am Phys Soc, **41**, 1452 (1996)
16. Area of Stochastic Scrape-off Layer for a Single-null Divertor Tokamak Using Simple Map
Fisher T***, Verma A and Punjabi A
Bull Am Phys Soc, **41**, 1452 (1996)
17. Calculation of the Area of Stochastic Layer for a Single-null Divertor Tokamak with the Effects for Dipole Coil Using Method of Maps
Basemore A***, Ali H, Watson M* and Punjabi A
Bull Am Phys Soc, **41**, 1452 (1996)

18. Characteristics of the Footprints of Field Lines for Variable Location of Plate for a Single-null Divertor Tokamak with the Effects of Dipole Coil Using Method of Maps
Burton J**, Ali H and Punjabi A
Bull Am Phys Soc, **41**, 1452 (1996)
19. Simple Map with Low MN Perturbation for a Single-null Divertor Tokamak with Constant Width of Stochastic Layer
Verma A, Smith T*, Punjabi A and Boozer A
Bull Am Phys Soc, **41**, 1484 (1996)
20. Symmetric Simple Map with Dipole Map for a Single-null Divertor Tokamak
Ali H, Watson M*, Punjabi A and Boozer A
Bull Am Phys Soc, **41**, 1484 (1996)
21. Arnold Diffusion in the Standard Map
Ali H, Truesdale R*, Punjabi A and Boozer A
!997 International Sherwood theory Conference, **3C43**
22. The Low MN Map for a Single-null Divertor Tokamak
Verma A, Smith T*, Punjabi A and Boozer A
!997 International Sherwood theory Conference, **3C44**
23. Footprint of Field Lines in a Single-null Divertor Tokamak with Dipole Perturbations Using the Method of Maps
Burton J**, Ali H and Punjabi A
1997 Council on Undergraduate Research Capitol Hill Poster Session, April 10 1997
1997 NAFEO High Tech Expo, Washington D. C., April 12 1997
1997 VA/MD/DC American Mathematics Association Regional Conference,
April 19 97
24. Modeling Shear in Magnetically Confined Plasma
Jones F**, Calvin M
1997 VA/MD/DC American Mathematics Association Regional Conference
25. Dwelling Times for Field Lines in a Single-null Divertor Tokamak Under the Effect of Dipole Perturbation Using the Method of Maps
Deal M***, Ali H and Punjabi A
To be presented at the 39th Annual Meeting, 1997 APS DPP, Pittsburgh, PA
26. Rotational Transform in Adjustable Shear Map for a Single-null Divertor Tokamak
Long C***, Lam M and Punjabi A
To be presented at the 39th Annual Meeting, 1997 APS DPP, Pittsburgh, PA

27. Arnold Diffusion in the Standard map With Variable Initial Conditions
McClendon B*** and Punjabi A
To be presented at the 39th Annual Meeting, 1997 APS DPP, Pittsburgh, PA
28. Symmetric Simple Map with Low MN Perturbations for Single-null Divertor Tokamak
Verma A, Punjabi A and Boozer A
To be presented at the 39th Annual Meeting, 1997 APS DPP, Pittsburgh, PA
29. Arnold Diffusion in the Standard Map with Aperiodic Perturbation
Ali H, Truesdale R*, Punjabi A and Boozer A
To be presented at the 39th Annual Meeting, 1997 APS DPP, Pittsburgh, PA
30. Educational and Outreach Programs at the HU Center for Fusion Research and Training
Huggins V and Punjabi A
To be presented at the 39th Annual Meeting, 1997 APS DPP, Pittsburgh, PA

Invited Seminars:

1. Method of Maps
Punjabi A
Institute of Plasma Research
University of Maryland, College Park, MD
Nov 1995
2. HU Fusion Initiative and Proposed Collaboration between DIII-D and HU CFRT
Punjabi A
DIII-D Advisory Committee Meeting
General Atomics, San Diego, CA
Feb 1996
3. Method of Maps for Divertor Tokamaks
Punjabi A
Institute for Fusion Studies
University of Wisconsin, Madison, WI
May 1996
4. Maps for Single-null Divertor Tokamak
Punjabi A
Institute for Plasma Research,
Ahmedabad, India
May 1996
5. Method of Maps for Divertor Tokamaks
Punjabi A
Plasma Fusion Center
Massachusetts Institute of Technology, Cambridge, MA
Aug 1996

II. EDUCATION, TRAINING, OUTREACH AND PUBLIC AWARENESS

A. INTRODUCTION

The HU CFRT has brilliantly succeeded in accomplishing the goals of its education, training and outreach mission. The HU CFRT has created an effective and functioning high school to PhD level pipeline for under-represented minorities and female students in fusion and related sciences. The HU CFRT has accomplished its goals in an exemplary manner - educated, trained and retained the under-represented minorities and female students in fusion and related sciences at high school, undergraduate and graduate (MS and PhD) levels; increased the number of minorities and females in physics, mathematics, computer science and engineering at BS, MS and PhD levels; and increased the number of minorities in private companies and academia at high level jobs with handsome salaries and excellent opportunities for professional advancement in future. The HU CFRT students have won prizes in national and regional competitions in research. The students have presented their research work at national and international professional meetings. They have brought us great pride and accolades. The details of these and other accomplishments appear in section B below.

The HU CFRT has accomplished all this in a short period of three years. The HU CFRT has accomplished this with the limited fiscal, human and material resources.

The HU CFRT has achieved this through a number of well-defined and carefully implemented programs for young female and under-represented minority students at high school, undergraduate and graduate (MS and PhD) levels.

The outreach and raising the public awareness of the importance of fusion science are an integral part of the HU CFRT activities. The center has had extraordinary successes in these areas too.

In the rest of this section, we give a summary of the programs developed and implemented at the HU CFRT during the three years of its existence. These programs made the above accomplishments possible.

i. Graduate Program: The goal of our graduate program is to attract, educate and train under-represented minority and female graduate students in fusion science, and provide them with opportunities to participate in research in fusion science and related areas. The students participate on-going research in the center. These projects range from the analysis of the effects of naturally occurring perturbations with low poloidal and toroidal mode numbers (low MN) on the footprint of field lines in divertor tokamaks to the development of a Monte Carlo code for transport due to MHD modes in tokamaks such as DIII-D and TFTR. The faculty in the center encourage and nurture the students to grow to their full potential without compromising the quality of research and the originality in their work. Graduate students also help in the training and mentoring of undergraduate and high school students. They also present the results of their research projects at APS DPP and Sherwood meetings.

The center presently has three PhD students and one MS student in its graduate program. Two graduate students graduated with MS in Applied Mathematics during the Summer 1997.

ii. Undergraduate Program: Undergraduate students come to the center with limited knowledge of fusion science and use of computers in research. Students are first taught the relevant basic concepts in physics, fusion science, mathematics and scientific programming. These students are also taught modeling, visualization of scientific data and how to use graphics software. Gradually they begin to participate in the on-going research projects in the center. At any particular time, the faculty in the center supervise projects ranging from iteration of simple maps for beginning undergraduate students to detailed comparisons between analytic approximations and numerical methods for more advanced students.

In their junior/senior years, these students participate and present their research work at professional meetings such as APS DPP, AAM, NAFEO High Tech Expo and Undergraduate Research Council. In fact, we are proud to report that some of these students have brought prestigious awards and honors to us. Franklin Jones received 2nd prize for best paper at the AAM regional meeting, and Joni Burton won a very competitive national contest to present her research on the Capitol Hill before US Senators and Congressmen.

The center presently supports three undergraduate students. Two students graduated with BS in Mathematics during the academic year 1996-97.

iii. Fusion Science and Related Courses: The faculty at the center teaches graduate courses in plasma physics, fluid mechanics and nonlinear science. The center has also developed undergraduate courses in fusion science and nonlinear science. These undergraduate courses have been approved by the full university faculty for physical science majors. The center plans to offer these courses in the future. The center is also planning to develop high school level fusion science and related courses through Hampton University High School Science Program (HU HSSP) for Hampton Roads Area. The center plans to use the experience gained in its Summer Fusion High School Workshops to develop these courses, and eventually to teach them through the HU HSSP. This will help us attract bright young minority and female students to fusion science in future.

iv. Fusion Science Seminars: The center has developed a partnership with the physics, mathematics, computer science and engineering departments. The center has conducted a series of seminars in fusion science. Students and faculty from the above departments attend the seminars. The center also invites prominent scientists and experts in fusion science to present colloquia at the center and share their expertise and the latest results of their investigations. Dr. Alkesh Punjabi has been invited to visit and give seminars at other fusion centers around the United States and abroad. This has allowed us to keep researchers at other centers abreast of our research, education, training and outreach activities.

v. Outside Resources: To supplement its resources, the center has reached out and obtained a variety of external resources for its education, training and outreach activities. The faculty in the center mentor students from other HBCU's as well as those supported by outside programs such as SEMS, McNair, AMP and NASA SHARP PLUS. These students come to the center with little or no background in fusion. They are mentored on one-on-one basis and taught the relevant material. At the end, these students have performed exceptionally well. Their excitement and interest in fusion science, scientific research and academics is greatly enhanced as a result of their research and learning experiences at the center. These students have authored/co-authored and/or presented contributed papers at the APS DPP annual meetings.

vi. Other Outreach and Public Awareness Activities: The HU CFRT is the first and only center for fusion research and training at an HBCU. In this context, the center has a unique role among the HBCUs. The center is at the forefront in providing continuing leadership and support for the nation's efforts to improve communication among scientific disciplines, and to raise the public awareness of the importance and significance of fusion research for the future of mankind and the nation - especially for the members of under-represented groups.

To this end, the center has planned, developed and implemented several activities. These range from speaking before local area high school students and their teachers, giving annual invited presentations on fusion science and its importance at the Quality Education for Minorities (QEM) Network Conferences. Dr. Punjabi, director of the center, was the keynote speaker at the 1996 HU Annual Research Day. The center has offered a series of fusion seminars for the HU College of Continuing Education Nuclear Engineering students. The center also makes annual presentations for students at all levels participating in variety of national programs conducted at Hampton. These programs include UniPhys, EARDA, AMP and NASA SHARP PLUS.

vii. Summer High School Fusion Science Workshops: The workshops are one of the activities of the center that are directed at attracting minority and female high school students to, and retaining them in, fusion science and related subjects. In fact, Tiffany Fisher, a participant of the 1996 workshop is now a freshman in our Undergraduate Program. The Center developed an exciting and very productive curriculum and palate of activities for the participants of the workshop. The first week usually consists of lectures on basic fusion science, computer programming, modelling and simulation, visualization of scientific data, basic HTML, WordPerfect, and the art of professional presentations. After these lectures, each student is assigned to a research mentor according to the student's interest in a specific research area and problem. The students have access to our computation laboratory seven days every week.

In 1996, the HU CFRT held its first High School Summer Fusion Science Workshop. Dr. Arun Verma coordinated this workshop. The workshop was conducted from June 19 to August 6. The center took students to visit the Princeton Plasma Physics Laboratory in Princeton, New Jersey and the Thomas Jefferson National Accelerator Facility in Newport News, Virginia. All four students presented their research projects at the Undergraduate, Education, Outreach poster session at the 1996 APS DPP annual meeting in Denver, CO.

In 1997, the center conducted its second High School Summer Fusion Science Workshop. Due to limited funding and manpower, the center accepted only three scholars - one female African American from Benjamin Banneker High School in Washington, D.C. and two male African Americans from John J Pershing High School in Detroit, Michigan and Menchville High School in Newport News, Virginia. Two of the students were supported by NASA SharpPlus and the other student was supported by Hampton University-Newport News Center for Excellence in Research, Teaching and Learning funded by NSF. Ms. Valencia Huggins coordinated this workshop. All three students have submitted abstracts to Undergraduate, Education, Outreach poster session of the 1997 APS DPP meeting in Pittsburgh. They plan to present the findings of their summer research projects at this meeting, depending on the availability of funds.

viii. Professional Meetings: It has long been documented that females and African-Americans are underrepresented in the physical sciences and engineering. The center attempts to attract these groups to fusion science and increase their participation. Such efforts include taking minority students at all levels to professional meetings such as the APS DPP and Sherwood meetings. Students present their research projects at these meetings. While at these meetings, the students have the opportunity to experience what it feels like to be a part of fusion community in particular, and the scientific research community in general. We hope that this may lead them to pursue careers in science, and perhaps in fusion. They also have the opportunity to meet and interact with prominent scientists and researchers in fusion which may not be possible otherwise.

ix. Inter-HBCU Fusion Science Collaboration: The HU CFRT has initiated a collaboration with a neighboring HBCU in a joint project to analyze fluctuation data in DIII-D.

We are very happy and proud to state that our successes in education, training and outreach and public awareness have been outstanding, especially in view of our limited resources and manpower. We can unequivocally say that we have done an exemplary job in fusion science education, training, outreach and public awareness for under-represented minorities and minority females at the graduate, undergraduate and high school levels.

The remainder of this chapter is organized as follows: In section B, we give details of our accomplishments during the last three years. In section C, we describe our plans for the next five years.

B. ACCOMPLISHMENTS

i. Graduate and Undergraduate Students Accomplishments:

We are very happy and proud to report the following graduate and undergraduate students accomplishments:

1. Terry Smith, an African American male graduate student in Applied Mathematics, defended his MS thesis in *low MN perturbations in divertor tokamaks* on June 11, 1997. Mr. Smith joined the center in the Fall 1994. During his tenure, he conducted research and presented or authored/co-authored contributed papers presented at the APS DPP and Sherwood meetings. He also participated in all the other activities of the center. He is presently employed by Lockheed-Martin in New York as an Applications Engineer at a handsome salary.
2. Richard Truesdale, an African American male graduate student in Applied Mathematics, defended his MS thesis on July 16, 1997 in *Arnold Diffusion in the Aperiodic Standard Map*. He started his employment in August 1997 with Lockheed-Martin in Springfield, VA as an Applications Software Engineer with a handsome salary. He was also offered a position at Hughes Network Systems Inc. in Germantown, MD at a better salary. He declined that offer. He also teaches part time at Bowie University. He plans to begin his PhD in Computational Science at George Mason University in Fairfax, VA in January 1998 while continuing to work full time at Lockheed-Martin. Lockheed-Martin will pay for his PhD. Richard was supported from Fall 1995 to Summer 1997 by Dr. Halima Ali's ONR research grant. He joined our center during the 1996 summer. He co-authored a contributed paper presented at the 1997 Sherwood meeting.
3. Michael Watson, an African American male graduate student in Physics, joined our center in the Fall 1994. During his tenure at center, Mr. Watson fully participated in the research and other activities of the center. He used the Symmetric Simple Map to represent unperturbed magnetic topology of a single-null divertor tokamak, and the Dipole Map to include the effects of dipole perturbations. He has presented findings of his projects at APS DPP and Sherwood meetings. Mr. Watson has completed all his course work and passed his qualifying exam at PhD level. He has also completed the necessary work and obtained the results for his thesis. He is planning to write and defend his physics PhD thesis during the academic year 1997-98. Even before completing his PhD thesis, Michael was offered a tenure track Assistant Professor position at the Fisk University. He joined Fisk University beginning Fall 1997. He plans to initiate a fusion science research program at Fisk University in collaboration with our center.

HU CFRT is proud to state that **Professor Robert Goldston** was highly impressed by Michael Watson when he visited Hampton to give a seminar in March 1995. Professor Goldston wrote a letter to Dr. Alkesh Punjabi after his return to PPPL. In the letter he stated that "...Your student Michael Watson asked me for these. I should say that in our brief discussion **I was very impressed with him...**"

4. Franklin Jones, an African American male undergraduate student in Mathematics, joined the center in the Fall 1994. He did research on **Modelling shear in a magnetically confined plasma** during his tenure at center. At the Virginia/Washington DC/Maryland American Association of Mathematics meeting in April 1997, he received 2nd prize for best paper. Franklin also received awards and honors from the Mathematics Department and from the Dean of the Hampton University School of Sciences.

5. Joni Burton, an African American female student joined the undergraduate program of our center in Summer 1996. She was then rising senior majoring in mathematics. Joni Burton won an intense national competition to present her research at the Undergraduate Research Poster Session on the Capitol Hill on April 10, 1997. This competition was organized by the Undergraduate Research Council. Only 46 research papers were selected from all over the nation. Ms. Burton's poster was the only paper in magnetic fusion. Her poster was visited and praised by Dr. Martha Krebs, Dr. Anne Davis and Senator Charles Robb on the Capitol Hill. Ms. Burton, Dr. Ali (her mentor in the center) and Dr. Punjabi (director of the center) also met with the Congressman Bateman and Senator Charles Robb and the aides to other Congressmen and Senators from Virginia on the Capitol to impress upon them the importance of fusion science research. Largely as a result of this and other efforts by the center, five Congressmen from Virginia - a record number- signed the letter in support of funding for fusion programs in 1997. On her return from Washington D. C., the *Hampton Life* - the Hampton University campus newspaper - published a long article titled "**Student Researcher Presents Future Energy Source to Congress**" in its May 1997 issue. The article carried her interview and a picture of Ms. Burton with Senator Charles Robb, Dr. Martha Krebs, Dr. Anne Davies, Dr. Ali and Dr. Punjabi on the Capitol. Copy of the article is enclosed.

At her graduation in May 1997, Joni received the *Adrian Freeman Award* - the highest honor accorded by Hampton University to a graduating senior - by the President William R. Harvey of Hampton University. She also received Award of Achievement - *Certificate for Distinction in Research* - from the Dean of the Hampton University School of Sciences and several awards and honors from the Mathematics Department. *The APS News* published a picture of Ms. Burton, Dr. Ali and Dr. Punjabi at the 1996 APS DPP Denever meeting on the front page of its February 1997 issue. Joni received letters of accolades and encouragements from Dr. William Harvey, President of Hampton University; and from Anne Davies, associate director for FES OER. Ms. Burton was selected for the PPPL 1997 Summer Research Opportunity Program. There she worked with Professor Ronald Davidson, the former Director of PPPL.

Given her extraordinary research and academic achievements, Joni could have received graduate scholarship at any top rated university. However, based on the her very positive experience with the center, she has chosen our center for her graduate work. Documentation of the above accomplishments of Joni is enclosed.

6. Tiffany Fisher, an African American female scholar, was a participant in the center's 1996 Summer Fusion High School Workshop. She presented the results of her project at the 1996 APS DPP Meeting in Denver. After her return from the APS DPP Denever meeting, the *Sun Journal*, a New Bern (her hometown), N. C. news-paper, published an article titled "*Fisher to Present Physics Paper*" with her picture in its October 1996 issue. Copy is included. With her exceptional academic achievements both at her school and at summer workshops in fusion and in music, she was offered full support at other universities in both Mathematics and Music. Her very positive experiences in our summer workshop led her to choose Hampton University so that she can join our center's undergraduate program.

7. The gradaute and undergraduate students conduct research and present their work at professional meetings and other venues. The following tables give information on the contributed papers authored/co-authored and/or presented by the students:

Table 1: Graduate students and the contributed papers authored/co-authored and/or presented by them at professional meetings

GRADUATE STUDENT	CONTRIBUTED PAPERS
Michael Watson	<p>Calculation of the Area of Stochastic Layer for a Single-null Divertor Tokamak with the Effects for Dipole Coil Using Method of Maps Basemore A, Ali H, Watson M and Punjabi A <i>Bull Am Phys Soc</i>, 41, 1452 (1996)</p> <p>Symmetric Simple Map with Dipole Map for a Single-null Divertor Tokamak Ali H, Watson M, Punjabi A and Boozer A <i>Bull Am Phys Soc</i>, 41, 1484 (1996)</p> <p>Catastrophe in the Stochastic Layer due to Dipole Perturbation Ali H, Watson M, Punjabi A and Boozer A <i>Inter Sherwood Fusion Theory Conf</i>, 1C20 (1996)</p> <p>Symmetric Simple Map for Single-null Divertor Tokamak Ali H, Watson M, Meyer C, Punjabi A and Boozer A <i>Bull Am Phys Soc</i>, 40, 1855 (1995)</p>

Terry Smith	<p>The Low MN Map for a Single-Null Divertor Tokamak Verma a, Smith T, Punjabi a and Boozer a <i>Proc Int Sherwood Theory Conf</i>, 3C44 (1997)</p> <p>Simple Map with Low MN Perturbation for a Single-null Divertor Tokamak with Constant Width of Stochastic Layer Verma A, Smith T, Punjabi A and Boozer A <i>Bull Am Phys Soc</i>, 41, 1484 (1996)</p> <p>Simple Map with Low MN Perturbations for a Single-null Divertor Tokamak Verma A, Smith T, Braswell T, Punjabi A and Boozer A <i>Bull Am Phys Soc</i>, 40, 1884 (1995)</p>
Richard Truesdale	<p>Arnold Diffusion in the Standard Map with Aperiodic Perturbation Ali H, Truesdale R, Punjabi A and Boozer A To be presented at the 1997 APS DPP Meeting</p> <p>Arnold Diffusion in the Standard Map Ali H, Truesdale R, Punjabi A and Boozer A <i>Proc Int Sherwood Theory Conf</i>, 3C43 (1997)</p>

Table 2: The HU CFRT undergraduate student researchers and the papers they presented at APS DPP and/or HU Research Day and other professional meetings

NAME	CONTRIBUTED PAPERS
Franklin Jones	Modelling Shear in a Magnetically Confined Plasma Jones F and Calvin M Proc HU Research Day (1997) Maryland/DC/Virginia Section of AAM Spring meeting (1997) Methods of Solving Boundary Value Problems for Second Order Differential Equations Jones F and Marable W Proc HU Research Day (1996)
Joni Burton	Footprint of Field Lines in a Single-null Divertor tokamak with Dipole Perturbation Using the Method of Maps Burton J, Ali H and Punjabi A Maryland/DC/Virginia Section of MAA Spring 97 meeting (1997) 11th annual NAFEO HighTech Expo, Washington, DC, (1997) Undergraduate Poster Session at Capitol Hill, Washington, DC (1997) Characteristics of the Footprints of Field Lines for Variable Location of Plate for a Single-null Divertor Tokamak with the Effects of Dipole Coil Using Method of Maps Burton J, Ali H and Punjabi A <i>Bull Am Phys Soc</i> , 41 , 1452 (1996)

8. Two graduate and two undergraduate students have graduated from the center during the academic year 1996-97 and summer 1997.

Table 3: Graduate students graduated from the center, their thesis advisors and title, and their present status:

NAME	RACE/GENDER	THESIS ADVISOR/ TITLE	DEGREE RECEIVED	PRESENT STATUS
Terry Smith	African American Male	Dr. Arun Verma low MN perturbations in divertor tokamaks	MS Applied Mathematics Summer 97	Applications Engineer Lockheed-Martin New York
Richard Tuesdale	African American Male	Dr. Halima Ali Arnold Diffusion in the Aperiodic Standard Map	MS Applied Mathematics Summer 97	Applications Software Engineer Lockheed-Martin Springfield, VA

Table 4: Undergraduate students graduated from the center during academic year 1996-97, their mentors and their present status:

NAME	RACE/GENDER	MENTOR/PROJECT	DEGREE RECEIVED	PRESENT STATUS
Franklin Jones	African American Male	Dr. Mark Calvin Modeling Shear in a Magnetically Confined Plasma	BS Mathematics	Employed by Lockheed-Martin in New Jersey
Joni Burton	African American Female	Dr. Halima Ali Dipole Map	BS Mathematics	Graduate Student at HU CFRT MS Candidate in Applied Mathematics

ii. Students in the Graduate Program of the Center:

At present, the center has four graduate students. The following two tables give information on these students.

Table 5: Graduate students supported by the center, their thesis advisors and their academic status

NAME	RACE/GENDER	THESIS ADVISOR	ACADEMIC STATUS
William Kengeffey	African American Male	Dr. Alkesh Punjabi	Candidate for PhD in Physics All required course work completed Passed Qualifying Exam at PhD level
Michelle Donalies	White Female	Dr. Alkesh Punjabi	Candidate for PhD in Physics
Joni Burton	African American Female	Dr. Halima Ali	Candidate for MS in Applied Mathematics

Table 6: Graduate student in the program but not supported by the center, his thesis advisor and his academic status

NAME	RACE/GENDER	THESIS ADVISOR	ACADEMIC STATUS
Michael Watson	African American Male	Dr. Alkesh Punjabi	Candidate for PhD in Physics All required course work completed Passed Qualifying Exam at PhD level

Table 7: Graduate students in the graduate program of the center and their projects:

GRADUATE STUDENT	THESIS/PROJECT
Michael Watson	Effects of Dipole Perturbations on the Footprint of Magnetic Field Lines on the Collector Plate in Single-null Divertor Tokamaks
William Kengeffey	Calculation of Drift Particle Trajectories in Non-singular Boozer Coordinates for Divertor Tokamaks
Michelle Donalies	Benchmarking of Divertor Maps with DIII-D Codes
Joni Burton	Non-singular Boozer Coordinates for Double-null Divertor Tokamaks

iii. Students in the Undergraduate Program of the Center: HU CFRT is presently mentoring three undergraduate students in fusion science. The following tables give information on the undergraduate students in the center:

Table 10: Undergraduate students mentored in fusion science research by our center, their mentors, race and academic classification

NAME	RACE/GENDER	MENTOR	CLASSIFICATION
Mellisa Davis	African American Female	Dr. Maria Lam	Senior Computer Science Major
Tiffany Fisher	African American Female	Dr. Arun Verma	Senior Mathematics Major
Gbemi Munis	African American Female	Dr. Nelson Jalufka	Freshman Electrical Engineering Major (transfer from Copping State College, MD with GPA 4.0)

Table 11: HU CFRT undergraduate student researchers, their research projects and source(s) of support

NAME	RESEARCH PROJECT	SUPPORT
Mellisa Davis	Trajectories of Suprathermal Alpha particles in Rippled Field of TFTR	HU CFRT Undergraduate Fusion Scholarship
Tiffany Fisher	Effects of Low MN Perturbations in Single-null Divertor Tokamak	HU Student Enhancement in Mathematics and Science (SEMS) Program funded by Office of Naval Research (ONR)
Gbemi Munis	2D VUV Spectroscopy in DIII-D Divertor	HU CFRT Undergraduate Fusion Scholarship

iv. Graduate Courses in Plasma Physics and Related Areas: The following plasma physics graduate courses were offered by HU CFRT:

Table 8: Graduate courses in plasma physics

GRADUATE COURSE	OFFERED IN	TAUGHT BY
PHY 716 Advanced Plasma Physics I	Fall 1995	Dr. Alkesh Punjabi
PHY 717 Advanced Plasma Physics II	Spring 1996	Dr. Alkesh Punjabi

The following related graduate course was offered for the first time at HU:

Table 9: Plasma physics related graduate course

GRADUATE COURSE	OFFERED IN	TAUGHT BY
MAT 631 Fluid Mechanics I	Fall 1996	Dr. Halima Ali

v. Outreach and Student Training in Summer 1995

In summer 1995, HU CFRT faculty mentored one undergraduate student and one high school student. The following table gives information on these students.

Table 12: Undergraduate and High school students mentored by the center researchers in summer 1995

NAME	RACE/GENDER	INSTITUTION	SUPPORTED BY
Tiffani Braswell	African-American Female	Largo High School Largo, MD	NASA SHARP PLUS NASA
Chaka Meyer	African-American Female	Howard University Washington, DC	AMP program NSF

These students worked with their mentors for eight weeks. For the first two weeks, students were given one-on-one instruction to build their basic understanding of the relevant concepts and to develop hands-on computer programming experience. During the third and fourth weeks, they were required to read books on fusion and to develop elementary understanding of the ideas in fusion science. They were required to write a journal. This journal was checked by their respective mentors. Then each student was assigned an original research problem to work on.

At the end of the eight week period, the students made well-received presentations before AMP and NASA SHARP Plus participants and mentors. The NASA SHARP Plus and AMP program organizers were highly impressed by the excellent job done by the center in mentoring their participant scholars during summer 1995, and these organizers felt that "excellent opportunities exist in your center for training and involving bright, young African American high school scholars in cutting edge research ... in an outstanding manner." (See attached letters).

Table 13: Undergraduate and high school students mentored by center researchers in summer 1995, their mentors and the contributed papers they co-authored at the 1995 APS DPP annual meeting.

STUDENT NAME	FACULTY MENTORS	CONTRIBUTED PAPERS
Tiffani Braswell	Dr. A Verma Dr. A Punjabi	Simple Map with Low MN Perturbations for a Single-null Divertor Tokamak Verma A, Smith T, Braswell T, Punjabi A and Boozer A <i>Bull Am Phys Soc</i> , 40 , 1884 (1995)
Chaka Meyer	Dr. H Ali Dr. A Punjabi	Symmetric Simple Map for a Single-null Divertor Tokamak Ali H, Watson M, Meyer C, Punjabi A and Boozer A <i>Bull Am Phys Soc</i> , 40 , 1855 (1995)

vi. HU CFRT Summer 1996 High School Fusion Science Workshop:

The first HU CFRT Summer Fusion High School Workshop was conducted in the Summer of 1996. Dr. Arun Verma coordinated this workshop. To our knowledge, this was the first fusion science workshop for under-represented minority high school students at an HBCU.

The NASA SHARP PLUS program is administered by QEM (Quality Education for Minority) for NASA. It places exceptional rising high school juniors and seniors in eight-week summer apprenticeships with mentors engaged in science or engineering related research in industry or on college campuses. The center was able to select four young scholars of the highest caliber from a national pool of high school students under this program to participate in the workshop. The center was afforded this opportunity based on its excellent performance in mentoring high school students under the NASA SHARP Plus and AMP programs the year before. Please see the attached letters. The NASA SHARP Plus program paid the stipend, room and board expenses, and most of the travel expense for the students.

Table 14: Participants of the 1996 Summer Fusion Science Research Workshop, their race and gender, the high school and the funding agency

STUDENT	RACE/GENDER	HIGH SCHOOL	FUNDING AGENCY
Alphonso Basemore	African-American Male	Mount Tabor High School, Winston-Salem, NC Rising Senior	NASA SHARP PLUS NASA
Tiffany Fisher	African-American Female	New Bern High School, New Bern, NC Rising Senior	NASA SHARP PLUS NASA
Jessica Hicks	White Female	Crest Senior High School Shelby, NC Rising Junior	NASA SHARP PLUS NASA
Michelangelo Whitten	Hispanic American Male	Bowie High School El Paso, TX Rising Senior	NASA SHARP PLUS NASA

During their tenure at HU CFRT, the students received a week of instruction in the basics of energy, plasma and fusion sciences. This was followed by a week of one-on-one mentoring under faculty mentors. The students also received instruction and training in the use of workstations and PC's, FORTRAN programming, modelling and simulation, visualization of scientific data, basic HTML, WordPerfect, graphics, research reports and technical paper writing. Students were then introduced to the concepts of magnetic confinement fusion and area-preserving maps.

The mentors were not alone in providing guidance and help to these students. The graduate students Michael Watson and Terry Smith, and our administrative secretary Valencia Huggins, were an integral part of the team that made the workshop an astounding success.

Each student was then assigned a specific original research problem to work on. The following table gives information on the students, their mentors and their research topics.

Table 15: The participants of the 1996 Fusion Science Research Summer Workshop, their mentors and their research project

STUDENT	FACULTY MENTORS	RESEARCH PROJECT
Alphonso Basemore	Dr. A Punjabi Dr. H Ali	Calculation of the Area of Stochastic Layer of a Single-Null Divertor Tokamak with the Effects of Dipole Coil Using Method of Maps
Tiffany Fisher	Dr. A Verma	Area of Stochastic Scrape-Off Layer for a Single-Null Divertor Tokamak using Simple Map

Jessica Hicks	Dr. M Calvin	Web Presentation to Raise Awareness of High School Students about Fusion Science
Michelangelo Whitten	Dr. M Lam	High Adjustable Shear Map for a Single-Null Divertor Tokamak

The research problems involved development of scientific computer codes. The students were required to be in the center's computational laboratory Monday through Thursday from 8:30 am to 5:00 pm. We were very glad to find that the students never had to be reminded of this requirement. The projects were simultaneously fun and challenging. These students voluntarily worked "overtime" on a daily basis. The students were taken to field trips to Princeton Plasma Physics Laboratory (PPPL) in Princeton University, NJ and the Thomas Jefferson National Accelerator Facilities (TJNAF) in Newport News, VA.

At the end of the eight week period, the students were required to make 30 minute presentations describing their research projects and the results before the mentors, the graduate and undergraduate students and staff in the center. The presentations were again made for a wider audience including the NASA SHARP Plus program participants, coordinators, and the dean and faculty of HU School of Sciences. The students surpassed all our expectations. Their presentations were excellent and professionally prepared and presented.

The students submitted abstracts for the 1996 American Physical Society Division of Plasma Physics (APS DPP) annual meeting. The APS DPP waived the registration fees for the students. They presented their posters under the Undergraduate Poster/Education Outreach section of the meeting. The following table gives information on the students and their contributed papers.

Table 16: Participants of the 1996 Summer Fusion Science Research High School Workshop and their contributed papers

STUDENT	CONTRIBUTED PAPERS
Alphonso Basemore	Calculation of the Area of Stochastic Layer of a Single-Null Divertor Tokamak with the Effects of Dipole Coil Using Method of Maps <i>Bull Am Phys Soc</i> , 41 , 4P 19 (1996)
Tiffany Fisher	Area of Stochastic Scrape-Off Layer for a Single-Null Divertor Tokamak using Simple Map <i>Bull Am Phys Soc</i> , 41 , 4P 17 (1996)
Jessica Hicks	Web Presentation to Raise Awareness of High School Students about Fusion Science <i>Bull Am Phys Soc</i> , 41 , 4P 14 (1996)
Michelangelo Whitten	High Adjustable Shear Map for a Single-Null Divertor Tokamak <i>Bull Am Phys Soc</i> , 41 , 4P 18 (1996)

The center's high school and undergraduate students' poster presentations at the 1996 APS DPP meeting in Denver, CO were an **astounding success**. To our knowledge, it was the **first time in history of APS DPP** that high school students presented contributed papers at an annual meeting. The depth and breadth of their knowledge in fusion science caught the attention of the entire fusion community. We have received several positive communications from prominent scientists within the fusion community. One of the high school students received a summer **internship offer from General Atomics**. An undergraduate student received **offer of a graduate fellowship from Auburn University**. These offers were made after these students explained their posters to the representatives of General Atomics and Auburn University at the Denver meeting.

The poster presentations were visited by scientists from **GA, MIT, LLNL, PPPL** and other prominent national and foreign research centers. A number of reprint requests were made by these visitors. Please see documentation.

The Directors of DIII-D and MIT PFC, Drs. **Thomas Simonen** and **Miklos Porkolab** visited the posters and had great praise for them. Dr. Porkolab expressed desire to become involved in the Hampton effort and offered to provide assistance in the high school workshops conducted by HU CFRT.

The Chairman of IEEE, Dr. **Jay Hyman**, suggested that these students should consider giving their posters at the IEEE Plasma Science meeting. Dr. Hyman plans to present the idea of starting an Education and Outreach Section in the IEEE meetings to the IEEE governing board.

The Assistant Director of MIT's Washington D. C. office, Mr. **Tobin Smith**, was very favorably impressed by the achievements of the students, and he suggested that the Center and these students consider testifying before the US Congress and Senate to help the cause of fusion science and education. It is his belief that the outreach and training activities of Hampton center are very impressive and a model to be emulated. Dr. **Steve Eckstrand** from US DOE also visited the posters and had high praises for them, and for the outreach and education activities of the HU CFRT.

The President-elect of APS DPP, Professor **Richard Hazeltine**, remarked that he had received a very positive response on the student poster presentations from the plasma science community at the meeting, and he felt that this outstanding success of educational and outreach activities of HU CFRT ought to be recognized and get strong media coverage within the scientific community. Please see the attached message to Ms. Valencia Huggins, the administrative secretary of our center.

The excitement, knowledge, experiences and success of the minority high school students in the summer workshop in fusion science also caught the attention of their parents, their local communities and news papers such as the *Sun Journal* in New Bern, NC, and the NASA SHARP PLUS administrators. We have received several positive calls and letters from students and their parents as well. Please see the documentation.

The February issue of *APS News* showed a picture of Ms. Joni Burton, Dr. Alkesh Punjabi and Dr. Halima Ali (Ms. Burton's mentor) on the front page. The picture shows them in front of Ms. Burton's poster at the 1996 APS DPP annual meeting in Denver. A reproduction of the APS News front page is shown attached.

vii. HU CFRT Summer 1997 High School Fusion Science Workshop:

The center conducted its second High School Summer Fusion Science Workshop in Summer 1997. Since the center had only three faculty mentors available during Summer 1997, the center could accept only three scholars in this workshop. Ms. Valencia Huggins coordinated this workshop. Each student was assigned to a research mentor according to the student's interest in a specific research area and problem. The students had access to our computation laboratory seven days every week.

Table 17: Participants of the 1997 Summer Fusion Science Research Workshop, their race and gender, the high school and the funding agency

STUDENT	RACE/GENDER	HIGH SCHOOL	FUNDING AGENCY
Bernard McClendon	African-American Male	John J Pershing High School, Detroit, Michigan.	NASA SHARP Plus NASA
Michelle Deal	African-American Female	Benjamin Banneker High School, Washington, DC.	NASA SHARP Plus NASA
Cleon Long	African-American Male	Menchville High School, Newport News, Virginia	HU-Newport News Center for Excellence in Research, Teaching and Learning NSF

In the workshop in the center, the students received instructions and training in the basics of energy, plasma and fusion sciences. They also received one-on-one instructions and training by their mentors to further their understanding of the subject and to introduce to relevant concepts such as magnetic confinement fusion, tokamaks, divertors and area-preserving maps.. They were also taught how to use workstations and PC's, FORTRAN programming, modelling and simulation, visualization of scientific data, basic HTML, WordPerfect, graphics, research reports and technical paper writing. The graduate student Richard Truesdale and the Administrative Assistant of the center Ms Valencia Huggins played an integral role in making the workshop an astounding success.

Table 18. Participants of the 1997 Summer Fusion Science Research High School Workshop and their contributed papers

STUDENT	FACULTY MENTORS	RESEARCH PROJECT
Bernard McClendon	Dr. A Punjabi	Investigation of Standard Map with Aperiodic Perturbation
Michelle Deal	Dr. Halima Ali	Analysis of Symmetric Simple Map with the Effect of the Dipole Map
Cleon Long	Dr. Maria Lam	Modelling Adjustable Shear for Single-null Divertor Tokamaks

At the end of the eight week period, the students were required to make 30 minute presentations describing their research projects and the results before the mentors, the graduate and undergraduate students and staff in the center. The presentations were again made for a wider audience including the NASA SHARP Plus program participants, coordinators, and the dean and faculty of HU School of Sciences. The students surpassed all our expectations. Their presentations were excellent and professionally prepared and presented. All three students submitted abstracts 1997 meeting of the APS DPP. They plan to present the findings of their summer research projects at the Undergraduate/Education/ Outreach poster session of the meeting in Pittsburgh depending on the availability of funds.

Table 19: The participants of the 1997 Fusion Science Research Summer Workshop and the titles of the Abstracts Submitted to 1997 APS DPP meeting

STUDENT	Contributed Papers
Bernard McClendon	Arnold diffusion in the standard map with variable initial conditions McClendon B and Punjabi A To be presented at the 1997 APS DPP meeting
Michelle Deal	Dwelling Times for Field Lines in a Single-Null Divertor Tokamak under the Effect of Dipole Perturbation Using the Method of Maps Deal M, Ali H and Punjabi A To be presented at the 1997 APS DPP meeting
Cleon Long	Rotational Transform in Adjustable Shear Map for a Single-null Divertor Tokamak Long C, Lam M and Punjabi A To be presented at the 1997 APS DPP meeting

viii. HU CFRT Fusion Seminars: The center initiated a series of seminars on fusion science in 1995 to expose the students and faculty from physics, mathematics, computer science and engineering to fusion science and the ongoing research in the center. See the following table.

Table 20: Fusion Science seminars

PRESENTER	DATE	TITLE
Punjabi A	October 95	Dipole Map for Tokamak Divertor
Marable W	November 95	Toroidal Eigenmodes of Ideal MHD

ix. Invited Colloquia at the Center: The center invited a number of prominent fusion scientists to give invited colloquia at the center. See the table below:

Table 21: Invited fusion science colloquia

INVITEE	AFFILIATION	DATE	TITLE
Dr. J Shebalin	NASA LaRC	17 Nov 94	Ideal, Incompressible, Homogeneous MHD Turbulence
Dr. G Vahala	College of William and Mary	27 Jan 95	Divertor Modelling in Tokamaks
Dr. R Goldston	PPPL	3 Mar 95	Route to Practical Fusion Power
Dr. D Montgomery	Dartmouth College	17 Mar 95	The Origin and Uses of Plasma Rotation
Dr. A Wootton	FRC Uni of Texas at Austin	7 Apr 95	Plasma Physics and Fusion
Dr. S McCool	FRC Uni of Texas at Austin	7 Apr 95	Etg Spherical Tokamak Plasma Experiment: Status and Goals
Dr. S Abdullaev	Courant Institute, NY Univ.	14 Apr 95	Self-Similarity of Hamiltonian Systems near the Hyperbolic Point and its Application to Tokamak Divertors
Dr. T Simonen	DIIL-D, General Atomics	20 Oct 95	Fusion Research: the Path to Starpower
Dr. P Mioduszewski	Oak Ridge National Lab	1 Aug 96	Introduction to Plasma-wall interactions in Magnetic Fusion Devices
Dr. B Welch	University of Maryland College Park	27 June 97	Laser Fusion

x. Public Awareness: We are very alive to the fact that the support of fusion science research is critically dependent on the public awareness of the importance of fusion to mankind in terms of an alternative energy source. Since the HU CFRT is the only fusion center at an HBCU institution the center is at the forefront of raising awareness within the African-American community in particular, and public in general. We avail ourselves of every opportunity and venue to do this. Our presentations are honest, factual, and at a level of complexity appropriate for the audience at hand. We will diligently continue our public awareness effort. The following invited presentations were given by faculty, graduate students and staff of the center for different audiences.

Table 22: Invited talks for public awareness of fusion science research and its importance

PRESENTER	DATE	TITLE	GIVEN AT
Ali H	Aug 1996	Introduction to Basic Fusion Science	HU Nuclear Engineering College of Continuing Education
Huggins V	Nov 1995	Educational and Outreach Programs at the HU Center for Fusion Research and Training	APS DPP annual meeting
Calvin M	Aug 1996	HU CFRT Computational and Research Facilities	HU Nuclear Engineering College of Continuing Education
Verma A	Sept 1996	Education, Training and Outreach at HU CFRT	HU Nuclear Engineering College of Continuing Education
Watson M	Oct 1996	A Journey into Fusion	HU Nuclear Engineering College of Continuing Education

Punjabi A	Oct 1994	HU Nuclear Fusion Initiative	Quality Education for Minority (QEM) Network Conference
	Apr 1995	HU CFRT	Technologies Opportunities Showcase (TOPS) NASA Langley, VA
	May 1995	Physics of Fundamental Energy Sources	Tabb High School in York County
	June 1995	Fusion and Tokamaks	HU UniPhys program in Physics Department
	June 1995	Nuclear Fusion	NASA SHARP PLUS
	July 1995	HU's Nuclear Fusion Initiative	HU EARDA
	Feb 1996	Tokamak Fusion Science Initiative	Key note Luncheon speaker at HU Research Day
	Apr 1996	HU's Nuclear Fusion Science Initiative	NIH Extramural programs
	Apr 1996	For all the right reasons	Video presentation for HU Recruitment
	June 1996	HU's Nuclear Fusion Initiative	NASA SHARP PLUS program
	July 1996	Plasma Physics	UniPhys program

Punjabi A	Sept 1996	Plasma Physics	HU Nuclear Engineering College of Continuing Education
	Feb 1997	Fusion Science and its Implications for Future of Mankind	1997 HU School of Science Annual Research Day
	June 1997	Fusion Science and Tokamaks	HU-Newport News Center for Excellence in Research, Teaching and Learning
	June 1997	Tokamaks and Divertors	NASA SharPlus
	Sept 1997	Fusion Science Research and Hampton University	NASA Administrators Fellowship Program

xi. Inter-HBCU Fusion Science Research Initiative: The center has initiated a collaborative research project with Dr. G Smith, an assistant professor of mathematics at Norfolk State University, and Dr. A Miamée, a professor of mathematics at Hampton, to apply their theory of nonstationary, harmonizable stochastic processes to analyze fluctuation data in tokamaks. We anticipate that this collaboration will expand and that faculty and students from other HBCUs will have opportunities to participate in fusion science research.

Table 23: Fusion science research collaboration between Hampton and Norfolk State University

COLLABORATOR	AFFILIATION	PROJECT
Dr. G Smith	Norfolk State University	Possible Application of theory of Nonstationary, Harmonizable, Stochastic Processes to Fluctuations in Tokamaks
Dr. A Miamée	Hampton University	

In summary, HU CFRT is very happy and proud to state that it has done an exemplary job of education, training and outreach activities at the graduate, undergraduate and high school levels, and of attempting to raise public awareness of the importance of fusion science research.