The H-1 National Plasma Fusion Research Facility Annual Report 2006

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The National Plasma Fusion Research Facility, located at the Plasma Research Laboratory, Research School of Physical Sciences and Engineering in the College of Science, The Australian National University, Canberra, Australia. http://prl.anu.edu.au/H-1NF.html
I INTRODUCTION

The H-1 Major National Research Facility is the Australian focus of basic experimental research on magnetically confined plasma, important in developing fusion energy, a clean, virtually inexhaustible energy source that powers the sun and stars. Plasma — ionised gas — makes up 99% of the visible universe, and plasma phenomena are important in everything from stars and space exploration to the processing of electronic materials. Plasma physics is thus a highly interdisciplinary endeavour because of the range of physics areas it encompasses (fluid, atomic, electromagnetic, optical and surface physics) and the diverse technologies employed in plasma experiments (electronics, radio-frequency technologies, magnetics, lasers, microwaves and spectroscopy).

The National Plasma Fusion Research Facility was developed from the “H-1 heliac” toroidal stellarator experiment in the Research School of Physical Sciences and Engineering at the Australian National University. The innovative plasma geometry of the H-1 heliac allows investigation of basic plasma physics, and exploration of ideas for improved design of the fusion power stations that will follow the ITER international fusion experiment. The objectives of this project are to provide:

• an experimental Facility with which Australian scientists, technologists and engineers can contribute to the world-wide effort to develop fusion as a future source of energy;
• opportunities for advanced research training for students of science and technology;
• a platform for the development of novel technological ideas that can be spun off for industrial use.

The development of the H-1 National Facility is supported by an $8.7M grant from the Department of Industry, Science and Resources, over a term which was recently extended to 2010. The Facility is operated by the Australian Fusion Research Group (AFRG), under the auspices of the Australian Institute of Nuclear Science and Engineering (AINSE). The AFRG consists of researchers in plasma physics from the Australian National University, the University of Canberra, the University of Sydney, and Flinders University of South Australia, and has recently joined interested scientists, engineers, students and others to form the Australian...
ITER Forum. Almost 100 strong, the forum aims to promote Australian research into fusion science and materials, and involvement in the international fusion experiment “ITER”.

The H-1 National Facility Heliac, operated by the Laboratory’s Toroidal Plasma group is a large toroidal helical-axis stellarator device that is used to carry out fundamental research in the physics of plasma confinement. The heliac magnetic field is produced by a precision three-dimensional magnetic system. The plasma is produced by high-power radio and microwaves, and its properties are measured by electric and magnetic probes, optical and microwave interferometry and scattering instruments. A particular focus of work on the heliac is the study of turbulent transport, flows, instabilities and the effect of magnetic configurations on plasma stability and confinement. Technologies originating in research on the heliac are also being applied to plasma diagnostics for experiments around the world, instruments for industry and defence, and wireless communication and radar (Section V). International collaborations include work with scientists from Japan, the United States, and Europe, and are elaborated on in section VI. In addition, the Laboratory also carries out research in plasma theory, simulation, and visualisation, in collaboration with staff from the Department of Theoretical Physics and the Department of Computer Sciences in the Faculty of Engineering and Information Technology.

The Laboratory is deeply involved in educating young scientists and engineers, through the supervision of post-graduate and fourth-year undergraduate research projects. We also regularly host students from around the world who can take advantage of the Laboratory’s special capabilities. Members of the Laboratory staff also have introduced new or contribute to existing undergraduate lecture and laboratory courses offered by the Department of Physics and the Department of Engineering in the ANU Faculties.

Figure 2: Bird’s eye view of the Facility, built around the H-1 heliac (centre, lid removed)
II EXECUTIVE SUMMARY

II.1 Highlights in 2006

The National Plasma Fusion Research Facility was established by the Australian National University and the Commonwealth of Australia through the Major National Research Facilities (MNRF) Programme. Funding was initially over the period 1997-2005 with an extension under existing funding until 2010. 2006 was the first full year under the new arrangements for the Operational Phase and marked the completion of the transition from parallel efforts of construction, commissioning and operation to a more efficient, largely automated mode of operation in support of research.

The Commonwealth MNRF funding of $8.7 million, building on the H-1 Heliac plasma confinement device, provided upgrades of the power supplies for plasma heating and magnetic field, control and data acquisition systems, advanced plasma measurement systems and other infrastructure, bringing the total value of the facility to in excess of $20 million. The mission of the Facility is to perform basic research into high-temperature plasma as part of an international program, whose ultimate aim is ecologically sustainable power generation by the controlled fusion of hydrogen isotopes. Important outcomes are development of plasma measurement systems, and technological spin-offs.

The Facility has met the majority of its milestones, and exceeded expectations in the area of remote control and technology development. This year many improvements were made to the Facility, including a substantial upgrade of the data system to a linux/MDSplus open source system, increasing speed by more than ten times, the construction of a new interchangeable foil soft X-ray detector, and the commissioning of a fast electronically scanning interferometer for measuring electron density profiles and their time evolution. The recently installed supersonic helium beam diagnostic for measurement of temporally and spatially resolved electron temperature and density came into full operation, in collaboration with the University of Sydney, and the fast electron beam mapping system has successfully mapped magnetic fields at the full operational magnetic field of 0.5 Tesla.

H-1NF provides an important resource to a wide range of researchers, national and international, world-class training to graduate students, and has generated a broad range of spin-offs for manufacturing, defence and communications industries. The extensive scope of these fundamental and technological challenges also equips the group to engage in a diverse range of related and complementary pursuits, which are summarised below in conjunction with the core plasma research from which they are derived.

In 2006 the Turbulence and Transport Studies Group led by Dr Michael Shats expanded the scope of their research; studies into the interaction between large coherent structures and turbulence in plasma were complemented with experiments in quasi-two-dimensional fluid turbulence. Among new important results was the discovery of the role of mean zonal flows in the formation of transport barriers in the improved confinement mode. The formation of zonal flow coincides with suppression of turbulence near the transport barrier. This confirms that spectral condensation previously suggested by the group as the universal mechanism of plasma self-organization, is indeed an important ingredient in the physics of improved plasma confinement. These results were published in Physical Review Letters. Hua Xia was awarded a PhD degree in 2006 and was appointed as a Postdoctoral Fellow with the group. The group had a central role in organizing 19th Canberra International Physics Summer School held at the Australian National University in January 2006 (convenor Dr. M.G. Shats) and the Workshop on Turbulence and Coherent Structures in Fluids, Plasma and Granular Flows. Drs. M. Shats and H. Punzmann have compiled and edited a book of Lecture Notes published
The Advanced Imaging and Inverse Methods Group led by Prof. John Howard undertakes research into passive (optical) and active (laser-based) techniques for plasma diagnostics, and their associated inverse methods, with applications in industry and medicine. This year saw a number of invited international talks on our patented optical coherence imaging (CI) technologies. Under contract to the Japanese Atomic Energy Agency, we have developed and successfully operated a compact CI system for Thomson scattering, and in addition have deployed a system for imaging of high temperature molten iron flows at Bluescope Steel. Supported by an Australian Research Council (ARC) Discovery Grant and in collaboration with researchers at Chalmers University in Sweden, the group has commenced research into suitable inverse techniques for microwave imaging of human tissue. Mr Scott Collis (PhD, Helium beam diagnostic) and Mr Ben Powell (MPhil, supersonic gas injector for plasma fuelling) completed their studies and submitted their theses this year.

Research on “BushLAN” is driven by the goal of using a wireless system to overcome the last mile Internet connectivity problem in regional and remote areas, and was a spin-off of research into using plasma antennas for radio frequency communications. This year saw the development of several important technologies for the new (television band: VHF/UHF) BushLAN broadband system. In an excellent example of research-lead teaching, digital signal processing software for the physical layer processing and the Intermediate Frequency (IF) amplifier was developed by students in the College of Engineering and Computer Science (CECS). BushLAN is topical again this year now that the Australian Government has rekindled the regional Internet debate with a 2 billion dollar investment on regional services. It is not clear that such services could be provided within the limitations of ADSL and WiMAX, and many now consider optical fibre to the home as the only way to achieve adequate broadband data rates.

The Plasma Configurations Group is applying an innovative data mining technique to the investigation a range of Alfvén-range instabilities in the H-1 plasma. The wide range of magnetic configurations and the precise computer control of H-1 make it uniquely suitable for fundamental studies of these instabilities, the understanding of which is crucial to the success of future large experiments, such as international fusion experiment (ITER). The cross-campus collaboration with Dr. M. Hegland of the Mathematical Sciences Institute has been extended internationally to include the Heliotron-J experiment in Japan, and a theoretical and computational collaboration with Dr. C. Nührenberg of the Max Planck Institute, Greifswald. In related work on plasma configurations, preliminary studies of the effect of magnetic islands on H-1 plasma have shown a possible link between island formation and the “Core Electron Root Confinement” phenomenon, which improves plasma confinement.

Looking to the future, outreach and development activities included the International Summer School and Workshop on Turbulence on Coherent Structure described above, which attracted a large attendance from both novices and experts in the field. Members of the Toroidal Plasma Group played a central role in the Australian ITER forum activities to promote an Australian involvement in the international fusion experiment (ITER) project, including many outreach presentations and organisation of the highly successful international workshop “Towards an Australian Involvement in ITER”.

Finally, continuing the restructure begun in 2005, we are pleased to welcome four new staff – Dr. Frank Detering, Research Fellow (Data Mining project jointly with COSNet), Dr Hua Xia, Postdoctoral Fellow, Ms Bronwyn Stuart, Administrator and Ananda Galagali, Electronics Technician.
II.2 Mission and Outcomes

The mission of the Facility is to:

(1) Perform research into the basic properties of magnetically-confined, high-temperature plasma as part of an international program, whose ultimate aim is ecologically sustainable power generation by the controlled fusion of hydrogen isotopes.

(2) Ensure that Australia is intellectually and technologically equipped to benefit from a future fusion power industry, with emphasis on the export of high-technology components needed by fusion power stations.

(3) Maintain Australia’s internationally recognised position of excellence in basic plasma physics and applications such as plasma diagnostics and plasma processing of semiconductors.

The research outcomes of the Facility include:

(i) A detailed understanding of the behaviour of hot plasma which is magnetically confined in the helical axis stellarator configuration (this forms part of an international program under the IEA Implementation Agreement on Stellarators, to which Australia is a party).

(ii) The development of advanced plasma measurement systems (“diagnostics”), integrating real-time processing and multi-dimensional visualisation of data.

(iii) Fundamental studies of turbulence and transport of particles and energy in confined plasmas.

(iv) Significant contributions to the global fusion research effort and an increased Australian presence in the field of plasma fusion power into the 21st century.

(v) Improvements in knowledge of basic plasma physics for applications such as plasma processing of semiconductors.

(vi) An important performance indicator was identified as “technological spin-off activities” in areas including instrumentation and techniques.

### Summary of outcomes in calendar year 2006

<table>
<thead>
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<th>Publications</th>
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<td>Books edited</td>
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<td>Refereed Journal Articles</td>
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<tr>
<td>Gigabytes data acquired</td>
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<tr>
<td>Patents</td>
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*Details in Section V.1, V.2*
III RESEARCH

III.1 Physics of zonal flows in toroidal plasma

The Turbulence and Transport Studies (TTS) group led by M. Shats continued studies into physics of large anisotropic structures which play crucial role in improving plasma confinement. Zonal flows which were first observed in 2002 by M. Shats and W.M. Solomon on H-1NF, have two main branches. The first one, the geodesic acoustic mode (GAM, figure 3), is the finite-frequency mode which develops only in a toroidal magnetic field due to the compressibility of the $E \times B$ flow in poloidal plane. Experimental results obtained by Drs. Michael Shats and Hua Xia have been analysed in collaboration with Dr. M. Yokoyama of NIFS (Toki, Japan) who developed numerical model to compute poloidal viscosity and geodesic curvature for the H-1 magnetic geometry. This allowed frequency of the GAM to be compared with its theoretical value. Good agreement with expected frequency confirmed experimental identification of GAM. These results have been published in [Shats M.G., Xia H., Yokoyama M. Plasma Physics and Controlled Fusion 48, S17 (2006)].

Another important result presented in this paper is the first experimental identification of the mean zonal in H-1. Mean zonal flows, also found in planetary atmospheres and oceans, are strong radially localised poloidally symmetric flows. Such flows are driven by smaller scale turbulent fluctuations, and in turn, affect parent waves. In some conditions mean zonal flows can couple some of its energy into GAMs, which act in this case as the energy sink for zonal flows. These results were summarized by M. Shats in his invited talk at the 9th International Workshop on Electric Fields, Structures and Relaxation in Plasmas (Rome, 2006). Hua Xia has given invited talk at the Workshop on Turbulence and Coherent Structures in Fluids and Plasma (Canberra, 2006) on the topic *Spectral transfer analysis in plasma turbulence*.

The discovery of the complex interplay between zonal flows and turbulence has become a focus of collaborative effort between the TTS group and Dr. S. Nazarenko (University of Warwick, UK) who visited H-1NF in December 2006.

**Structure of transport barriers in high confinement mode**

Several years of intense research into physics of the transport barriers conducted by the Turbulence and Transport Studies group resulted in 2006 in the discovery which pinpoints a physical mechanism responsible for the shape of plasma radial profiles in improved confinement mode. New results published in December 2006 in Physical Review Letters [H.
Xia, M. G. Shats, H. Punzmann, *Phys. Rev. Lett.* **97**, 255003 (2006) demonstrated that the position of the density pedestal, figure 4, which develops in plasma in high confinement mode, is perfectly correlated with the development of strong zonal flow in the transport barrier region. Zonal flows have been suspected to play important roles in the plasma confinement, yet there had been no evidence of their role in H-mode. Experimental results obtained in H-1NF show that the strongest zonal flow develops right at the foot of the density pedestal. It is very likely that zonal flow locally reduces radial transport of particles and leads to a steepening in the density profile.

The discovery that the location of the zonal flow determines the location of the transport barrier is of great importance for the future fusion reactor. Optimization of the radial profiles of the plasma parameters in fusion reactors is the ultimate goal of the transport barrier studies around the world.

### III.2 Advanced Imaging and Inverse Methods

The Advanced Imaging and Inverse Methods (AIIM) Group (J. Howard, S. Collis, D. Oliver, D. Byrne, B. Powell) led by Prof John Howard undertakes research into passive (optical) and active (laser-based) techniques for plasma diagnostics, and their associated inverse methods, with applications in industry and medicine. To complement this work, we also investigate issues relating to inverse methods and tomography whereby useful information can be extracted from line-of-sight integrated measurements by applying appropriate mathematical transformations.

This has been a particularly busy year, with a number of invited presentations and external contracts. Supported by an Australian Research Council (ARC) Discovery Grant and in collaboration with researchers at Chalmers University in Sweden, the group has commenced research into suitable inverse techniques for microwave imaging of human tissue. Dr George Warr will join AIIM as a postdoctoral fellow working on this project in early 2007. Mr Scott Collis (PhD, Helium beam diagnostic) and Mr Ben Powell (MPhil, supersonic gas injector for plasma fuelling) completed their studies and submitted their theses this year. In addition, Prof Howard served as a member of the international panel charged with reviewing the diagnostic systems planned for the W7-X superconducting stellarator under construction in Greifswald Germany.
Coherence imaging systems
This year has seen continued development of our patented 2-d coherence imaging systems, which have been pioneered by AIIM in the last few years. These systems have underpinned successful PhD programs by Dr Clive Michael (2004) and Fenton Glass (2005). The results have clarified the details of ion force balance in argon plasmas (Michael), and have revealed the dynamics of the force balance in plasmas dominated by large coherent instabilities (Glass). The systems, and their variants, have been adopted by a number of laboratories around the world, including at the RFX experiment in Italy, on the WEGA stellarator in Greifswald, Germany and for the KSTAR tokamak at the Korean National Fusion Research Centre.

Quadrant coherence imaging systems
In 2005 we reported the design, construction and successful deployment of the first 2-d single-snapshot coherence imaging camera for ultrafast high-resolution spectral imaging. The system uses polarization optical components to produce quadratures of the coherence image simultaneously at the four corners of a fast CCD camera. This has powerful ramifications for high-resolution 2-d Doppler imaging of plasmas. This new capability was recognized with an invitation to present the work to the American Physical Society Topical Meeting on High Temperature Plasma Diagnostics in Virginia in July.

A following invited presentation to the 16th International Toki Conference on “Advanced Imaging and Plasma Diagnostics” expanded this work to consider the implications of CI for velocity field tomography. First reconstructions of ion temperature perturbations associated with a large scale global instability observed in argon discharges in H-1, and obtained by F Glass and C Michael, were reported at the meeting. The reconstructed emissivity contours (solid contours) are consistent with earlier measurements obtained using the scanning interferometer.

Thomson Scattering System for JAEA
Under contract to the Japanese Atomic Energy Agency, we have developed and calibrated a compact CI system for Thomson scattering. First measurements will be undertaken on the TPE-RX reversed field pinch in Japan in March 2007. Details of the instrument design and construction were reported at the Toki conference in Japan in November.
Interferometry studies of Alfvén eigenmodes in H-1

Figure 5: a) Fast scanning electron density projections from H-1, showing both quiescent and unstable discharges, obtained by changing the rotational transform slightly. The apparent fine spatial variation is predominantly aliased temporal oscillation. b) Experimentally observed spatial mode structure in $\bar{n}e$ (line integrals). Two shot by shot scans show reproducibility. c) Preliminary eigenmode structure as computed by CAS3D. Several differences prevent detailed comparison of b) and c).

Detailed measurements of a full projection of the modal structure of the density perturbation associated with the Alfvén Eigenmodes has been obtained on a shot-to-shot basis using a scannable heterodyne 2mm interferometer system. The system was constructed by Mr D. Byrne in the course of his honours project. The projections, which will be tomographically inverted as part of the thesis work of one of our PhD students, show clear signatures consistent with $m=3$ and $m=4$ eigenmodes identified by the Mirnov coils and can give the absolute level of the local density fluctuation amplitude for comparison with theoretical models. Preliminary results from the CAS3D MHD stability code in collaboration with Dr. C. Nührenberg in this regime show eigenmode structures, with a varying degree of localisation as illustrated in Figure 5c, which should be distinguishable experimentally. This work has been conducted in close collaboration with Dr Blackwell and Mr D Pretty.
III.3 Plasma Configurations

H-1 has unique flexibility of plasma configuration, and it is found that plasma formation is very sensitive to the configuration, for example the rotational transform or twist per turn, controlled by the parameter $k_h$, the fraction of current in the helical conductor. This is illustrated by swept density (ELSI) data obtained by the AIIM group as shown in figure 6.

![Figure 6](image6.png)

**Figure 6.** The dependence of electron density profiles ($\times 10^{18} \text{m}^{-3}$), important for Alfvén resonance, on configuration ($k_h=I_{\text{Helix}}/I_{\text{Ring}}$). Lines of constant $\iota$ are overlaid, illustrating resonance and shear. Operation is restricted to the range $k_h > 0.16$ and inverted $n_e$ data are not available for $k_h > 1$.

**Analysis of MHD instabilities**

Over the same range of configurations, magnetic fluctuations in the range 1-200kHz are observed when plasma is produced by RF heating (7MHz, 50-100kW) in gas mixtures of hydrogen and helium or deuterium, chosen to optimise plasma production by hydrogen minority heating and to enable spectroscopic diagnostics. Signals range from highly coherent, often multi-frequency in sequence or simultaneously, to approaching broadband. Figure 7 shows an example of coherent modes exhibiting Alfvén scaling with the time varying plasma density ($1/\sqrt{n_e}$).

If the dominant frequencies are plotted against configuration parameter, patterns become evident from the large data set or 100 shots, and 60 time intervals within each shot, both in magnetic field fluctuations, and in the ELSI electron density data (fig. 8).

![Figure 7](image7.png)

**Figure 7:** Evolution of frequency spectra during a discharge for $k_h=0.3$. Electron density ($n_e$) is shown for reference, $1/\sqrt{n_e}$ is overlaid (dotted) to illustrate Alfvénic scaling.

![Figure 8](image8.png)

**Figure 8:** Data from Mirnov coils and swept mm wave interferometer plotted against configuration.
Data mining, the process of extracting useful information from large databases, such as in bioinformatics research to discover useful information in genetic code, is used to extract key features from this data. Our data mining process is largely automated and groups the thousands of structures found into a small number of clusters (~10), of similar mode structure. This year, the clusters corresponding to the “V” shaped features were isolated, and found to have remarkably consistent scaling with the Alfvén frequency, within a constant factor of ~ 3, which is possibly due to uncertainties in the mass density, as shown in figure 9.

![Figure 9](image)

Figure 9: $k_i V_A$ (line) compared with observed frequency (kHz, × × ×), both normalized by $\sqrt{n_e}$ for vicinity of the two Y shaped clusters in Fig 8 ($\iota \sim 4/3$ (a) and 5/4 (b)). The lower graphs show the same scaling against $n_e$.

A tentative explanation is that in low shear configurations near (but not at) resonance, global Alfvén eigenmodes (GAEs) are predicted to cluster in the spectral gap $0 < \omega < |k_i| V_A$ which decreases as the transform approaches resonance ($\iota = 5/4, 4/3$); the mode twist approaches that of the field lines and $k_i$ (and hence $\omega \rightarrow 0$). The scaling with both rotation transform and mass density is convincing, and efforts are underway to understand the origin of the constant factor.

The technique is also being applied to the newly installed poloidal Mirnov array on the Heliotron-J stellarator as part of a collaboration with the Kyoto Plasma Group. Heliotron-J is similar in shear profile to H-1, but has neutral beam heating, and can produce a wider range of Alfvénic instabilities. Initial work by Dr. Blackwell in reducing power supply noise effects in January was successful, and the data mining process was successfully applied to a small test set in preparation for future campaigns.

**Magnetic Island Configurations**

The combination of precisely controllable power supplies, the flexible coil set and the permanently installed wire-tomography mapping system make H-1 uniquely equipped to study magnetic configurations. This year the microstepping controller driving the array of 64 wires was upgraded to complete a scan in 14 seconds, so that surfaces can be mapped at highest fields used in regular operation. This speed improvement also facilitates studies of magnetic islands.
IV AUSTRALIAN FUSION RESEARCH AND THE H-1NF

Large Device Physics on a University Scale: H-1NF is large enough to permit plasma experiments of fusion interest, but remains a university-scale activity that favours innovative and exploratory experiments. H-1NF thus complements the large national laboratory experiments in Japan, Europe, and the US, which have rigorous technological and scheduling constraints. Recent experiments on H-1NF have explored the details of turbulent particle and energy transport and the transition to improved confinement regimes in low-power plasmas that facilitate diagnostic access, but preserve the essential physics seen in larger, hotter plasmas that are more difficult to study. Novel diagnostic methods using tomography, spectroscopic temperature and flow visualisation, and cross-correlation spectroscopy are being developed on H-1NF for eventual exploitation on larger experiments around the world.

Scientists in Australia have long been active in fusion research, working on small university experiments and as members of international teams on large experiments overseas. The development of H-1NF offers Australian researchers the opportunity to do experiments on a facility that is large enough to produce hot plasmas with temperatures approaching 500 eV ~ 5 million degrees C.

IV.1 Sydney University

Supersonic injector system for measurement of electron temperatures in H-1

In a very fruitful collaboration with A/Prof James and Dr D Andruczyk at the University of Sydney, Scott Collis (PhD thesis submitted this year) has managed to obtain for the first time, spatially resolved measurements of the evolution of the electron temperature in both electron and ion cyclotron heated discharges in hydrogen/helium gas mixtures at 0.5T in the H-1 heliac. The Sydney team have constructed a multi-pulse, highly collimated and intense helium supersonic jet that can probe the H-1 plasma cross section. Using a collisional-radiative model (CRM), the ratio of the intensities of light emission from singlet and triplet electronic state transitions of helium atoms excited by electron impact in the plasma can be used to infer the local electron temperature and/or density. With knowledge of the injected jet density, the plasma electron density distribution obtained using the electronically scanned interferometer, and the spectroscopically estimated $T_e$ profile, we have used the CRM to predict the expected evolution of the emission brightness as a function of position in the plasma. The excellent agreement with measurements is a powerful cross-check on the estimated electron temperature profiles.

IV.2 Australian Fusion Research: The Australian ITER Forum

The original Australian Fusion Research Group has recently joined interested scientists, engineers, students and others to form the Australian ITER Forum. Almost 100 strong, the forum aims to promote Australian research into fusion science and materials, and involvement in the international fusion experiment “ITER”.

Members of the Toroidal Plasma Group played a central role in the Australian ITER forum activities to promote an Australian involvement in the international fusion experiment (ITER) project, including many outreach presentations and organisation of the highly successful international workshop “Towards an Australian Involvement in ITER”.

The workshop, supported by DEST, outreach funds from H-1NF, COSNet, ANSTO, AINSE and several leading Universities, brought together the representatives of the stakeholders if Australia is to participate in the largest scientific experiment in the world. The experiment seeks to develop the science and technology necessary for the harnessing of nuclear fusion to provide clean, safe, renewable electrical energy. Attendees included senior staff from the ITER central body and most of the international ITER partners, and representatives from Industry and Government.

Potential benefits for Australia include improving Australian science and scientific industry, training and retention of scientific skills and the fostering of international research links will enhance Australia's overall scientific credentials. Australia is also in the advantageous position of possessing a large number of resources of rare metals (Li, V, Ta) that could be used for construction and fuelling of not only the ITER project, but in future electrical power plants.

The workshop highlighted areas of existing and emergent Australian research excellence, and explored how these could be mapped to ITER programs. Inspired by the success of the workshop, a strategy document is being developed with the aim to secure a formal participation in ITER, and the establishment of a national or international centre to consolidate Australia's fusion research efforts.

AINSE provided 6 competitive student bursary awards, to bring students – especially those considering honours or postgraduate studies - to the workshop. At least one prospective graduate student was inspired to take a PhD in fusion science, and several in honours.

Figure 11: Australian ITER Workshop attendees, Manly, 2006
V FACILITY PROMOTION

In 2006, the main outreach was associated with the Australian ITER Forum, in particular the workshop described in Section IV, in addition to promotional and awareness activities undertaken by staff to promote the Facility. These include the publishing of recent research results in a number of refereed journals (see Section VI.I) and presentations by researchers at several national and international conferences. A number of collaborative ventures with national and international partners, government and private industry were also undertaken (see Section VII). Visits to the Facility by national and international researchers and by prospective science students were organised, and service was provided by staff to a number of outside organizations.

These activities are summarised below

V.1 Publications

Book Chapters:
Shats, M., Xia, H.,
*Experimental Studies of Plasma Turbulence in Turbulence and Coherent Structures in Fluids Plasmas and Nonlinear Media*

Refereed Journal Articles:
Collis, S., Howard, J., Blackwell, B., Powell, B., Carlsson, P., and Abelsson, M.,
*A supersonic gas injection system for fueling and probing fusion plasmas*
*Plasma Sources Science and Technology* 15:4 (2006)

Howard, J.
*Application of polarization interferometers for Thomson scattering*

Shats, M., Punzmann, H., and Xia, H.
*Turbulent Particle Transport in the Context of L-H Transitions*

Howard, J., and Oliver, D.
*Electronically swept millimeter-wave interferometer for spatially resolved measurement of plasma electron density*
*Applied Optics* 45 (2006)

Howard, J.
*High-speed high-resolution plasma spectroscopy using spatial-multiplex coherence imaging techniques*

Gesto, F., Blackwell, B., Charles, C., and Boswell, R.
*Ion Detachment in the Helicon Double-Layer Thruster Exhaust Beam*
*Journal of Propulsion and Power* 22 (2006)
Shats, M., Xia, H., and Yokoyama, M.  
Mean $E \times B$ flows and GAM-like oscillations in the H-1 heliac  

Linardakis, P., Borg, G., Martin, M.  
Plasma-based lens for microwave beam steering  
Electronics Letters 42 (2006)

Dewar, R., Nührenberg, C., and Tatsuno, T.  
Quantum Chaos Analysis of the Ideal Interchange Spectrum in a Stellarator  

Xia, H., Shats, M., and Punzmann, H.  
Strong $E \times B$ Shear Flows in the Transport-Barrier Region in H-Mode Plasma  

Oliver, D., Howard, J., Tekke, S., Pretty, D., and Blackwell, B.  
Three view electronically scanned interferometer for plasma electron density measurements on the H-1 heliac  

Shats, M., Punzmann, H., and Xia, H.  
Turbulent Particle Transport in the Context of L-H Transitions  

Shats, M., Xia, H., and Punzmann, H.  
Zonal flows GAM and radial electric field in the H-1 heliac  

Invited Talks:

B.D. Blackwell, J. Howard, M.J. Hole, D.G. Pretty and D.R. Oliver,  
The H-1 National Plasma Fusion Research Facility, and the Prospects for Stellarators in the Quest for Fusion Power  

J. O'Connor and M.J. Hole,  
The potential for Australian involvement in ITER  

T. Hatae, J. Howard, Y. Hirano, H. Koguchi, O. Naito, S. Kitamura  
Thomson scattering diagnostics with Fourier transform spectroscopy
12th Meeting of the ITPA Topical Group on Diagnostics, Princeton 2006

J. Howard, F. Glass, C Michael,
Doppler spectroscopy and tomography of plasmas (Invited)
16th Toki Conference, Japan 2006

J. Howard

High-speed high-resolution plasma spectroscopy using spatial-multiplex coherence imaging techniques (Invited)

Associated Publications (AFRG)

Namba S, Andruczyk D, Takiyama K, et al.
Development of supersonic metastable helium pulsed beam source for plasma diagnostics
JAPANESE JOURNAL OF APPLIED PHYSICS PART 1-REGULAR PAPERS BRIEF COMMUNICATIONS & REVIEW PAPERS 45 (10B): 8099-8103 OCT 2006

Andruczyk D, Tarrant RN, James BW, et al.
Langmuir probe study of a titanium pulsed filtered cathodic arc discharge
PLASMA SOURCES SCIENCE & TECHNOLOGY 15 (3): 533-537 AUG 2006

A short-pulsed compact supersonic helium beam source for plasma diagnostics
PLASMA DEVICES AND OPERATIONS 14 (1): 81-89 MAR 2006

McMillan BF, Storer RG
SPECTOR3D: a resistive magnetohydrodynamic stability code for stellarators
JOURNAL OF PLASMA PHYSICS 72: 829-832 Part 6 DEC 2006

McMillan BF, Dewar RL
Stellarator stability with respect to global kinetic ballooning modes
NUCLEAR FUSION 46 (4): 477-486 APR 2006

Dewar RL, Nuhrenberg C, Tatsuno T
Quantum chaos analysis of the ideal interchange spectrum in a stellarator
JOURNAL OF PLASMA PHYSICS 72: 1239-1242 Part 6 DEC 2006

Hole MJ, Hudson SR, Dewar RL
Stepped pressure profile equilibria in cylindrical plasmas via partial Taylor relaxation
JOURNAL OF PLASMA PHYSICS 72: 1167-1171 Part 6 DEC 2006

B.D. Blackwell, J. Howard, M.J. Hole, D.G. Pretty, and D.R. Oliver,
The H-1 National Plasma Fusion Research Facility and the Prospects for Stellarators in the Quest for Fusion Power”
B. D. Blackwell, M.J. Hole, J. Howard and J. O'Connor
*Fusion Research: Australian Connections, Past and Future*,


**Patents**

**J. Howard**  
Method and apparatus for the estimation of the temperature of a blackbody radiator. US patent #7001068 (21-2-2006)

**V.2 Service to Outside Organisations**

**Dr. B. Blackwell**  
Member of the International Union on Pure and Applied Physics (IUPAP) Commission on Plasma Physics, C16  
Member of the Executive Committee of the International Energy Agency (IEA) Implementing Agreement on the Development of the Stellarator Concept.

**Dr J Howard,**  
Deputy Chair, ACT branch of the Australian Institute of Physics.  
Member, Editorial Board, Plasma Physics and Controlled Fusion (PPCF)

**Dr John Howard** served as a member of the International review panel of W7-X diagnostic systems, Max Planck Institute for Plasma Physics, Greifswald, Germany, July 2006

**V.3 Outreach Activities**

**Dr Michael Shats** convened the 19th International Canberra Physics Summer School On Turbulence and Coherent Structures in Fluids, Plasma and Granular Flows in Canberra in January.

**Dr Michael Shats** was Co-Chair of the Workshop on Turbulence and Coherent Structures, ANU, Canberra, which followed the Summer School.

**A New Plasma Section**, chaired by Dr. Shats was added to the *Workshop on Fluid Mechanics* in Melbourne in December 2006.

**Dr. Boyd Blackwell** made presentations to Engineers Australia in Sydney, the University of Melbourne and Queensland on the H-1 National Facility and prospects for Australian involvement in ITER.

Dr John Howard was program chair for the Australian ITER forum workshop “Towards and Australian Involvement with ITER”, Sydney, Oct 2006

Contributed to Australian ITER forum submissions to:
The Parliamentary Inquiry into Developing Australia's non-Fossil Fuel Energy Industry,
The Joint NCRIS Planning Forum
The Energy Forum of the NSW Department of State and Regional Development
Technology Gaps Working Group of the Council of Australian Governments
The Prime Minister's Uranium Mining, Processing and Nuclear Energy Review
VI COLLABORATION, EDUCATION AND TRAINING

VI.1 Collaborative Ventures

Dr Boyd Blackwell
Project: Data mining and Analysis of MHD fluctuations in Heliotron-J
Partners: Dr K. Nagasaki

Dr John Howard
Project: Installation of Coherence imaging system
Partners: University of Sydney

Project: Microwave tomography of human tissue
Partner: Professor Mikael Persson, Chalmers University, Sweden

Project: Optical coherence imaging for Thomson scattering
Partner: Dr T Hatae, Japan Atomic Energy Agency

Project: Optical imaging systems for thermography and slag/iron discrimination at a molten iron furnace
Partner: Mr B Scott, Dr R Nightingale, Bluescope Steel Limited, Port Kembla

Project: Coherence imaging studies of the Hanbit Mirror and KSTAR tokamak
Partner: Dr J Chung, Korean National Fusion Research Center

Professor J. Howard, Dr. M. Shats and Dr. B. Blackwell
Project: Development of Diagnostic Imaging Systems for the Sydney University High Current Pulsed Arc
Partners: Professor M. Bilek, Dr R. Tarrant, Dr G. Warr and Professor D. Mackenzie, University of Sydney

Dr M.G. Shats
Project: Confinement Studies in Stellarators
Partner?

Project: Non-local transfer in plasma turbulence
Partners: Dr S. Nazarenko, Mathematics Research Centre, Warwick University, United Kingdom

Dr Gerard Borg
Project: Collaboration with Standard communications on ARC grant and application for Scientific license for radio emission
Partners: Mr Zu Zhao, Mr David Dries, Mr Guong Long, Mr Joel Leong,
VII CONTRIBUTION TO AUSTRALIAN INDUSTRY

VII.1 Radiofrequency Research

BushLAN

During this year enormous progress was made in the development of radiofrequency and telecommunications courses in the College of Engineering and Computer Science with ten students in all taking part in the BushLAN research effort. The highlight of the year was the submission and successful assessment of Mr Jeta Vedi’s Master’s thesis entitled “A Study of MAC Protocols for Long Range Wireless Networks”.

The BushLAN project investigates development of novel techniques for the transmission of high data rates over a long range. This work is a research effort aimed at using specialised radiofrequency and signal processing techniques to combat the seemingly insurmountable compromise between long range and high data rates. Given that wireless networks are theoretically capable of supporting amongst the highest bandwidths of all telecom technologies with the least cost and overhead of installation (wireless or otherwise), it is important to devote efforts to investigate techniques to exploit this.

![Block diagram of the UHF WRAN BushLAN up/down converter or IF strip](image)

During 2006 we began to investigate a number of new wireless technologies. In particular we progressed in the development of VHF/UHF device to serve the upcoming Wireless Regional Area Network Standard (802.22 WRAN). An exchange student Mr Lukas Kull of the Eidgenossische Technische Hochschule Zuerich (ETHZ) Switzerland developed the IF strip shown in figure 12.

This system will be capable of 2 Mbps over 30 kms and will be instantaneously tunable across the entire TV band from 45 - 820 MHz.
Miniature Plasma Switches For Personal Communications Systems.

Motorola is sponsoring a PhD thesis to investigate the use of plasma as a switch as the switching or tuning element in personal communications systems. The aim of this work is to investigate plasma as a candidate for a switching medium between antennas in multi-band mobile phones.

This year saw numerous fundamental experimental investigations of a miniature plasma device shown in Figure 2. The device is constructed from polycarbonate and consists of a small chamber through which a gas can be pumped. There are four gold plated electrodes, two for firing the discharge via a d.c. voltage and two for the plates of the RF capacitor.

Measurements of the plasma discharge properties included breakdown (Paschen curves) current and voltage characteristics and measurements of impedance and non-linear behaviour. Figure 13 shows the discharge structure for two different currents at 3.5 mbar. The light emission shown is that of the discharge near the cathode (right) and anode (left).

![Figure 13](image)

**Figure 13.** Photograph of the miniature plasma switch, and b) Light emission patterns at 3.5 mbar with terminal plasma drive voltages and currents of 863 V/200 μA (upper) and 999 V/267 μA (lower)

To measure impedance and scattering parameters, the plasma micro-device was mounted on an RF test rig as shown in Figure 4. The test rig consists of a carefully designed transmission line PCB that permitted the terminals of the plasma capacitor to be connected to a Rohde and Schwarz ZVB 20 Vector Network Analyser, illustrated in figure 14.

![Figure 14](image)

**Figure 14.** The miniature plasma switch mounted on a (much larger) RF analyser test rig for characterisation.
Figure 15 shows a comparison of the measured ratio of capacitance to the vacuum value and the theoretically computed ratio based on a cold plasma model. At high frequencies and currents there is a six-fold increase in capacitance. Notice that surprisingly a reduction in capacitance can also be observed.

![Figure 15](image)

**Figure 15.** (a) Measured and (b) modelled inter-electrode capacitance of the plasma micro-capacitor.

### VII.2 Thermography applications at Bluescope Steel Limited

With the success of the quadrant CI systems, we constructed and trialled a similar 4-quadrant system for broadband, two-colour imaging of molten iron streams at Bluescope Steel. A single point dispersive spectrometer was also deployed during these tests. Unfortunately, unexpected, unidentified spectral line contamination of the blackbody spectrum within the passbands chosen for the study has compromised the interpretation of the 4-quadrant imager data. This will be redressed in future work. Nevertheless, preliminary outcomes have been sufficiently encouraging that Bluescope Steel Limited has committed $120K towards a joint linkage proposal that was submitted to the ARC in November this year.

![Figure 16](image)

**Figure 16:** The AIIM group: Scott Collis, John Howard, David Oliver, Ben Powell and Michael Hush (foreground
VIII STAFFING AND ADMINISTRATION

VIII.1 Management Structure of the H-1 National Facility

Under the new agreement with the Commonwealth, the Board structure has been adapted from the original structure to recognise the industry links, the spin-off potential and to allow for development of collaborative proposals covering a broader range of areas such as advanced energy, fusion science and technology and materials.

The management structure of the Facility is shown below. This structure involves three major organisations, namely the Department of Education, Science and Training, (DEST), the Australian Institute of Nuclear Science and Engineering, (AINSE) and The Australian National University, all of which have input into the decisions made by the H-1NF Board. The Board, and the Management Committees, have direct impact on the Facility. The higher level role of the Australian Fusion Research Group has been subsumed by the larger entity presently known as the “Australian ITER Forum”, and at the lower levels, by incorporating active external researchers in the management committee.

The management committee is based on annual roundtable gatherings of proponents that we have found be very successful. This provides a clear mechanism for proponent organizations and users to have effective input to Facility operations planning, and equitably allows for the Director to also be a Facility user. It combines the roles of the previous Steering and Operations Committees, and consists of the Facility Director and Manager, leaders of Facility research pursuits, and representatives or nominees of user’s organisation and proponent organizations, one per organisation.

This committee meets annually with the full membership, and weekly, in a reduced form (just the members that are on site). At annual meetings, scientific and technical operational plans and associated budgets are developed, including Facility upgrades, collaborations, and research training plans, consistent with this Business Plan. At weekly meetings, the reduced Management Committee executes the operational plan and schedules experiments. The role of AINSE lies mainly in the facilitation and coordination of Australian collaborations and the allocation of travel funds in support of this.

The Director oversees the implementation of the operation plan in accordance with the contract, including reporting to the Board.

Figure 17: H-1NF Management Structure
VIII.2 Membership of the H-1NF Board

Members of the H-1NF Board are:

Chair  A/Prof. J.O’Connor, PhD DSc ANU
H-1NF Director (ex officio)  A/Prof. B.D. Blackwell,

Ex Officio ANU

Director, RSPhysSE, ANU (ex officio)  Prof. J. Williams, BSc PhD NSW, FAA, FTSE, FAIP, FIEAust
DVC Research  Prof. L. Cram, BSc BE PhD Syd, FAIP, FRAS

Representatives of Proponent Institutions

Univ. of Sydney Representative  Prof. M. Bilek, BSc Syd, PhD Camb
ITER Forum Representative  Prof. Robin G. Storer, BSc, PhD Adelaide

Representative of Government Research Organisations

Chief of Materials, ANSTO  Dr George Collins
Scientific Secretary, and  Dr. D. Mather, BSc PhD UNSW, Dip Ed STC
AINSE Representative (ex officio)

Experts in Associated Fields

Plasma Physics  Prof. Robert Dewar/Prof. Cheetham (Alternate)
Spectroscopy, Optics  Prof. Halina Rubinsztein-Dunlop
Turbulence, Fluids  Prof. Julio Soria
Environment  Dr. J. Baker, MSc PhD Qld, OBE, FTSE

Corresponding International Member(s) connected with:
International Stellarator Research.  (Prof. J. Harris)
ITER project/fusion research  (to be appointed)

Industry Representatives from relevant Materials, Energy or Minerals fields (To be appointed)

Minutes Secretary  Ms. B. Stuart

VIII.3 ANU and AFRG Staff

Academic Staff

A/Prof. B.D. Blackwell, Director
A/Prof. J. Howard, (ANU) H-1NF Diagnostics Coordinator
Dr. G.G. Borg, (ANU)
Dr. M. Shats, (ANU)

Research Engineer and H-1NF Facility Manager

Dr. Horst Punzmann, BSc Polytech Regensburg
Technical Staff
Costanzo Costa (until May)
Ananda Galagali (from August)
Mark Gwynneth
Mr. J. Wach

Administrative Staff
Ms. H.P. Hawes (until July) /Ms Bronwyn Stuart (from August)

Visiting Fellows
Joe Baker, MSc PhD Qld, OBE, FTSE
Marcela Bilek, Bsc Syd, PhD Camb.
Andrew Cheetham, BSc PhD Flinders
Roger Gammon, Btech PhD Brunel, FinstP, Cphys, MIE Aust, CP Eng, FAIE, FAIM
Sydney Hamberger, PhD DSc Lond, FAIP (Emeritus Professor)
Dennis Mather, BSc PhD UNSW, Dip Ed STC
John O'Connor, BSc PhD DSc
Anthony Sproule, ME UT Syd, GradDipOR NSW IT
Robin G. Storer, Bsc PhD Flin.
Masayuki Yokoyama, National Institute for Fusion Science, Japan

Post-graduate Students
Mr Michael Anderson, BEng ANU,APA/ASS
Mr Scott Collis, BSc Sydney, ANUPTS
Mr Ben Heslop, BE ANU, APA(I)
Mr Santhosh Kumar, BSc Calcutta, MSc Pune, ANUPTS
Mr David Oliver, BSc Wollongong, APA/ASS
Mr David Pretty, BSc Melbourne, ANUPTS
Mr Jeta Vedi, BE BCom ANU, APA, ASS
Mr Ben Powell, Bsc BLM, CQU, ANU/MPhil

Honours Students
Mr David Byrne* The Australian National University PRL
Mr Ahmed Benazir Faculty of Engineering and Information Technology PRL
Bathiya Senanayake Faculty of Engineering, ANU Gerard Borg
Ronald Keikothaile Faculty of Engineering, ANU Gerard Borg
Francis Grealy Faculty of Engineering, ANU Gerard Borg
John Pillans Faculty of Engineering, ANU Gerard Borg
Stefan Foudoulis Faculty of Engineering, ANU Gerard Borg

Summer Scholars
IX GRANTS AWARDED

Australian Research Council (ARC) Grants and Awards
Dr B.D. Blackwell and Dr M. Hegland
High-performance Computational Data-mining Techniques for Feature Detection in Complex
Time Series from Large-scale, Networked Plasma Experiments
2004 – 2006 $195,000

ARC LIEF
Dr J.Howard, M. Persson
Development of microwave tomography techniques and inverse methods for biomedical imaging
2006 – 2008 $370,000

ARC Linkage Projects
Dr G.G. Borg, Professor J.H. Harris and Dr H.M Jones
VHF Wireless Technologies for Last-mile Internet Access in Regional Australia
2003 – 2006 $ 138,198

Bluescope Steel
Dr J. Howard
Research & Development of Coherence Pyrometry Technology within the Ironmaking Process
2006 – 2006 $31,500

Japan Atomic Energy Agency
Dr J. Howard
Development of Fourier spectrometers for JT-60U Thomson scattering
2006 $86,000

DEST
Innovation Access Programs
Dr J. Howard
Studies of High Temperature Edge Plasma Confinement Physics using New Hyperspectral Imaging Systems
2004 – 2006 $173,690

DISR
Professor J. Harris et al.
National Plasma Fusion Research Facility
April 1997 – May 2005
June 2005 – June 2010 $8,700,000

Dr G. G. Borg
Teaching Grant Advanced Telecoms
2006 $10,000
X  PROJECT PROGRESS VERSUS MILESTONES

Project Milestones

The Table below lists the 2006 project progress against milestones from the MNRF contract. All but three (light highlights) are complete. Helium line ratio spectroscopy has been commissioned and tested and will replace Thomson scattering. Operation at full field (1 Tesla) will be deferred at least until towards the end of the new contract, until results with the new ECH and ICH power sources have produced several publications, and until it can be determined if power line compensation should be implemented.

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Plan</th>
<th>Revised</th>
<th>Achieved</th>
<th>Status/Progress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnet Power Supply</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5 Tesla</td>
<td>5-1998</td>
<td>2-1999</td>
<td>Achieved</td>
<td></td>
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<tr>
<td>1.0 Tesla</td>
<td>4-2000</td>
<td>2010*</td>
<td></td>
<td>*Deferred for review under new contract</td>
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<tr>
<td>ECH Plasma Heating</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 kW into dummy load</td>
<td>3-1998</td>
<td>6-1997</td>
<td>Ahead</td>
<td></td>
</tr>
<tr>
<td>150 kW into plasma</td>
<td>6-1998</td>
<td>4-2002</td>
<td>Shot 47355</td>
<td></td>
</tr>
<tr>
<td>ICH Plasma Heating</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demonstrate rf heating at low field (0.1T)</td>
<td>9-1997</td>
<td>9-1997</td>
<td>on time</td>
<td></td>
</tr>
<tr>
<td>100 kW into plasma</td>
<td>10-1998</td>
<td>6-1999</td>
<td>Ahead</td>
<td></td>
</tr>
<tr>
<td>200 kW into plasma</td>
<td>6-1999</td>
<td>4-2002</td>
<td>Shot 47034 (Argon)</td>
<td></td>
</tr>
<tr>
<td>High Power Heating upgrade</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Decide balance of ECH/RF(ICH)</td>
<td>6-1999</td>
<td>2008</td>
<td></td>
<td>250kW RF modulator more consistent with current manpower</td>
</tr>
<tr>
<td>Diagnostics</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Solid state spectrometer for flow and temperature profiles, operational</td>
<td>7-1997</td>
<td>7-1997</td>
<td>on time</td>
<td></td>
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<tr>
<td>Multiple retarding field energy analyzer operational</td>
<td>8-1997</td>
<td>2000: Complete: (Supplanted by advanced probe array and Doppler spectroscopy)</td>
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<td>2D tomographic density interferometer operational</td>
<td>4-1998</td>
<td>4-1998</td>
<td>on time</td>
<td></td>
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<tr>
<td>Multiview Thomson scattering operational</td>
<td>9-1998</td>
<td>9-2006</td>
<td>Successfully replaced by Helium line ratio</td>
<td></td>
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<tr>
<td>2D visible Doppler spectroscopy system operational</td>
<td>1-1999</td>
<td>9-2000</td>
<td>installed 9/1999</td>
<td></td>
</tr>
<tr>
<td>Multiview Soft X-ray diagnostic operational</td>
<td>3-1999</td>
<td>2002</td>
<td>New Array Complete, awaits Electronics</td>
<td></td>
</tr>
<tr>
<td>Data system</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real time experimental participation demonstrated from remote sites—</td>
<td>7-1998</td>
<td>6-1998</td>
<td>Ahead</td>
<td></td>
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Milestone completion status for H-INF Development
XI FINANCIAL STATEMENTS

Because of requirements to report financial matters by financial year, four quarterly statements are included here, up to and including April-June 2007.

Note: These copies will be replaced by clean copies of the FINAL versions that have been transmitted to DEST (which will be otherwise unchanged)

<table>
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<th>MNRF CASHFLOW REPORT</th>
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**Draft Cashflow Report**

**Name:** Lorraine Piper

**Position:** Senior Accountant, Special Purpose Funds
The Australian National University

**Unused Funds Available for this Period**

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<th>Amount</th>
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**Next Quarter**

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<th>Amount</th>
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**Cash Carried over from previous quarter**

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<tr>
<td>A2</td>
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**RECEIPTS**

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<td></td>
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<tr>
<td>Partner Contributions</td>
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<td></td>
</tr>
<tr>
<td>Other Sources</td>
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<tr>
<td>Interest</td>
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<td>TOTAL RECEIPTS</td>
<td>B1</td>
<td>B2</td>
</tr>
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<td>13,800.39</td>
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**EXPENDITURE**

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<td>Power Supply</td>
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<td>3,145.00</td>
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<td>Heating Systems</td>
<td>4,590.00</td>
<td>1,145.00</td>
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<td>Plasma Diagnostics</td>
<td>52,523.19</td>
<td>35,145.00</td>
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<td>Heliac Infrastructure</td>
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<td>Other Support Costs</td>
<td>14,022.72</td>
<td>80,000.00</td>
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<td>TOTAL EXPENDITURE</td>
<td>C1</td>
<td>C2</td>
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<td>89,636.47</td>
<td>124,145.00</td>
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**CASH BALANCE**

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<th>Next Quarter</th>
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<td>D2</td>
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<td>1,307,636.43</td>
<td>1,307,636.43</td>
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</table>
**MNRF CASHFLOW REPORT**

**NATIONAL PLASMA FUSION RESEARCH FACILITY**

for the quarter Ended: **31-Dec-06**

**Position:** Senior Accountant, Special Purposes Funds
The Australian National University

**AUTHORIZATION SIGNATURE**

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<th>Next Quarter</th>
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<tr>
<td><strong>Cash Carried over from previous quarter</strong></td>
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**RECEIPTS**

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<tr>
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<td>Non-MNRF Program Funds</td>
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<td>Partner Contributions</td>
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<td>Interest</td>
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<td>TOTAL RECEIPTS</td>
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<td><strong>B2 0.00</strong></td>
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**EXPENDITURE**

<table>
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<th>Next Quarter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Supply</td>
<td>2,197.01</td>
<td><strong>5,000</strong></td>
</tr>
<tr>
<td>Heating Systems</td>
<td>0.00</td>
<td><strong>1,500</strong></td>
</tr>
<tr>
<td>Plasma Diagnostics</td>
<td>28,191.08</td>
<td><strong>25,000</strong></td>
</tr>
<tr>
<td>Heliac Infrastructure</td>
<td>5,322.53</td>
<td><strong>25,000</strong></td>
</tr>
<tr>
<td>Other Support Costs</td>
<td>80,659.28</td>
<td><strong>15,000</strong></td>
</tr>
<tr>
<td>TOTAL EXPENDITURE</td>
<td><strong>C1 116,280.20</strong></td>
<td><strong>C2 45,000.00</strong></td>
</tr>
</tbody>
</table>

**CASH BALANCE**

<table>
<thead>
<tr>
<th></th>
<th>This Period</th>
<th>Next Quarter</th>
</tr>
</thead>
<tbody>
<tr>
<td>CASH BALANCE OF ACCOUNT</td>
<td><strong>D1 1,208,197.53</strong></td>
<td><strong>D2 1,208,197.53</strong></td>
</tr>
</tbody>
</table>
# MNRF CASHFLOW REPORT

## NATIONAL PLASMA FUSION RESEARCH FACILITY

Report for the quarter Ended: 31-Mar-07

**Name:** Lorraine Piper  
**Position:** Senior Accountant, Special Purposes Funds, The Australian National University

<table>
<thead>
<tr>
<th>Unused Funds Available for this Period</th>
<th>Next Quarter</th>
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</thead>
<tbody>
<tr>
<td>Cash Carried over from previous quarter</td>
<td>A1 1,208,197.53</td>
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## RECEIPTS

<table>
<thead>
<tr>
<th>This Period</th>
<th>Next Quarter</th>
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<tbody>
<tr>
<td>MNRF Program Funds</td>
<td>0.00</td>
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<tr>
<td>Non-MNRF Program Funds</td>
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<tr>
<td>Partner Contributions</td>
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<td>Other Sources</td>
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<tr>
<td>Interest</td>
<td>8,190.99</td>
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<td>TOTAL RECEIPTS</td>
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## EXPENDITURE

<table>
<thead>
<tr>
<th>This Period</th>
<th>Next Quarter</th>
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<tbody>
<tr>
<td>Power Supply</td>
<td>4,283.86</td>
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<tr>
<td>Heating Systems</td>
<td>22.45</td>
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<td>Plasma Diagnostics</td>
<td>17,451.47</td>
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<td>Helvac Infrastructure</td>
<td>53.72</td>
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<td>Other Support Costs</td>
<td>10,591.32</td>
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<tr>
<td>TOTAL EXPENDITURE</td>
<td>C1 32,402.62</td>
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## CASH BALANCE

<table>
<thead>
<tr>
<th>This Period</th>
<th>Next Quarter</th>
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<tbody>
<tr>
<td>CASH BALANCE OF ACCOUNT</td>
<td>D1 1,183,985.70</td>
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<tr>
<td>ACRONYMS</td>
<td>Definition</td>
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<tr>
<td>-------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>ABC</td>
<td>Australian Broadcasting Commission</td>
</tr>
<tr>
<td>AFRG</td>
<td>Australian Fusion Research Group</td>
</tr>
<tr>
<td>ANU</td>
<td>Australian National University</td>
</tr>
<tr>
<td>AINSE</td>
<td>Australian Institute of Nuclear Science and Engineering</td>
</tr>
<tr>
<td>CDX-U</td>
<td>Current Drive Experiment-Upgrade</td>
</tr>
<tr>
<td>CQU</td>
<td>Central Queensland University</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>DISR</td>
<td>Department of Industry, Science and Resources</td>
</tr>
<tr>
<td>DSTO</td>
<td>Defence Science and Technology Organisation</td>
</tr>
<tr>
<td>DT</td>
<td>Deuterium-Tritium</td>
</tr>
<tr>
<td>ECH</td>
<td>Electron Cyclotron Heating</td>
</tr>
<tr>
<td>ECRH</td>
<td>Electron Cyclotron Resonance Heating</td>
</tr>
<tr>
<td>ELSI</td>
<td>Electronically Swept Interferometer</td>
</tr>
<tr>
<td>FEIT</td>
<td>Faculty of Engineering and Information Technology</td>
</tr>
<tr>
<td>H-1NF</td>
<td>H-1 (Heliac) National Facility</td>
</tr>
<tr>
<td>IAS</td>
<td>Institute of Advanced Science</td>
</tr>
<tr>
<td>JET</td>
<td>Joint European Torus</td>
</tr>
<tr>
<td>LCD</td>
<td>Liquid Crystal Display</td>
</tr>
<tr>
<td>LHD</td>
<td>Large Helical Device</td>
</tr>
<tr>
<td>MEMS</td>
<td>Micro-Electronic Mechanical Switch</td>
</tr>
<tr>
<td>MDS</td>
<td>Model Data System</td>
</tr>
<tr>
<td>MHD</td>
<td>Magneto-hydrodynamic</td>
</tr>
<tr>
<td>MOSS</td>
<td>Modulated Optical Solid State</td>
</tr>
<tr>
<td>NIFS</td>
<td>National Institute for Fusion Science</td>
</tr>
<tr>
<td>OVMS</td>
<td>Open Virtual Machine Operating System</td>
</tr>
<tr>
<td>ORION</td>
<td>Oak Ridge Ion</td>
</tr>
<tr>
<td>PIC</td>
<td>Particle-in-Cell</td>
</tr>
<tr>
<td>PIN</td>
<td>P-type (intrinsic layer) n-type diode</td>
</tr>
<tr>
<td>PC</td>
<td>Personal Computer</td>
</tr>
<tr>
<td>RF</td>
<td>Radio-frequency</td>
</tr>
<tr>
<td>RIEFP</td>
<td>Research Infrastructure Equipment and Facilities Scheme</td>
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<tr>
<td>SOFT</td>
<td>Spread-Spectrum Optical Fourier Transform</td>
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<tr>
<td>SPIRT</td>
<td>Strategic Partnerships with Industry - Research and Training Scheme</td>
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<tr>
<td>SP3</td>
<td>Space Plasma and Plasma Processing</td>
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<tr>
<td>TFTR</td>
<td>Tokamak Fusion Test Reactor</td>
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<tr>
<td>TJ-II</td>
<td>Torus de la Junta de l’Energia Nuclear</td>
</tr>
<tr>
<td>UC</td>
<td>University of Canberra</td>
</tr>
<tr>
<td>VNC</td>
<td>Virtual Network Computer</td>
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<tr>
<td>WKB</td>
<td>Wentzel-Kramers-Brillouin</td>
</tr>
</tbody>
</table>