# The H-1 National Plasma Fusion Research Facility Annual Report 2004

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The National Plasma Fusion Research Facility
Located at the Plasma Research Laboratory,
Research School of Physical Sciences and Engineering, Institute of Advanced Studies
The Australian National University, Canberra, Australia.

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, the energy source powering 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 and microwaves, spectroscopy).

The National Plasma Fusion Research Facility is being developed from the “H-1 heliac” toroidal stellarator experiment in the Research School of Physical Sciences and Engineering in the Institute of Advanced Studies 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 over eight years (1997-2005) from the Department of Industry, Science and Resources. The Facility is operated by the Australian Fusion Research Group (AFRG), which acts under the auspices of the Australian Institute of Nuclear Science and Engineering (AINSE). The AFRG consists of researchers in plasma physics and fusion from the

Figure 1: Various aspects of the facility (from top) visualization, plasma, diagnostics, the vacuum vessel, coil set and communications spinoffs.
Australian National University, the University of Canberra, the University of Sydney, and Flinders University of South Australia. International collaborations include work with scientists from Japan, the United States, and Europe, and are elaborated on in section VI.

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.

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 research and fourth-year undergraduate research projects. We also regularly host students from around the world who come to 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: The H-1 magnetic field coils, copper bus-bars, with Rob Davies adjusting bolt tensions.
II EXECUTIVE SUMMARY

II.1 Highlights in 2004

2004 was a productive year – the group moved into purpose-built laboratories in the new Weigold wing, work began on recasting the business plan to suit the operational phase of the facility, and the automation of H-1 was largely completed. Automation by the use of programmable logic controllers accelerates data-taking, improves the quality of data by extensive logging of measurements, and reduces the manpower required to operate the H-1 facility. As a result over 3,100 plasma pulses were recorded, amounting to 20 Gigabytes of raw data. New systems included a directional gas injection system (DISH – section III) and an ECRH incident energy monitor.

The heliac is also being used to develop experimental techniques that can be applied on large-scale international fusion experiments. Dr. John Howard and his colleagues in the Advanced Imaging and Inverse Methods Group have developed a series of instruments known as coherence imaging spectrometers. These are novel imaging spectrometers that use electro-optic technology and advanced image and signal processing to determine temperatures and flows in radiating media such as plasmas. This year Dr Howard has expanded the development of novel multi-spectral imaging systems with two recent provisional patent applications on instruments suitable for industrial colour pyrometry for temperature and emissivity imaging, and for high-speed high-resolution spectroscopic imaging. Unique “camera” instruments similar to those successfully employed on the H-1 heliac, and optimized for high-speed plasma Doppler studies have been commissioned under contract to Consorzio RFX Italy, Max Planck Institute for Plasma Physics (Germany) and the Korean Basic Science Institute. Another system is being developed for the University of Sydney with LIEF grant support. The visible emission tomography system based on a 55 channel fibre coupled coherence imaging spectrometer demonstrated its full potential by imaging intensity, ion temperature and flow in an argon plasma, and by reconstructing both normal surfaces and magnetic islands.

Ground-breaking experimental studies of plasma turbulence in the heliac by Dr. Michael Shats and his colleagues demonstrated the role of self-organisation, zonal flows and spectral energy transfer in regulating the outward transport of particles and achieving enhanced plasma confinement. This physics is essential to achieving efficient confinement of fusion plasmas, but is also a universal phenomenon in complex dynamical systems, such fluid flows and both Earth and planetary atmospheric physics, and is a rapidly developing research area worldwide. The heliac has been shown to be a uniquely effective experimental environment for precise studies of these phenomena.

The computer controlled precision magnet power supplies (12,000,000 Watts) together with the above-mentioned automation allow precise adjustment of the complex magnetic geometry. With a large operational range of magnetic fields (>20:1), gases, and the variety of heating systems, H-1NF is the most flexible plasma machine in the world. This facilitates detailed investigation of the effect of spatial resonances on magnetic configuration and
confinement. Experiments carried out by Dr. Boyd Blackwell, Prof. Jeffrey Harris and their colleagues demonstrated the sensitivity of confinement and fluctuations to these resonance effects, and a related collaborative experiment on the large D3D tokamak facility in the USA demonstrated the use of spatially-resonant magnetic fields to control the stability of the plasma edge to sudden pulses of heat and particle flux which present control problems for fusion reactors.

III RESEARCH

III.1 Self-Organization of Plasma Turbulence in the H-1 Heliac

Results obtained by the Turbulence and Transport Studies group led by Dr. M. Shats suggest that the plasma turbulence in a toroidal magnetic field, such as the plasma in the H-1 heliac, self-organizes into large structures. This makes plasma turbulence similar to the two-dimensional (2D) fluid turbulence observed, for example in planetary atmospheres and oceans. Though intuitively perceived as a more chaotic state (e.g., turbulent versus laminar flows), the 2D turbulence often shows a tendency to self-organize leading to a higher degree of order. Zonal flows or poloidally and toroidally symmetric potential structures in plasma are expected to play significant roles in magnetically confined plasma.

The first experimental identification of finite-frequency zonal flow was presented by M. Shats and W. Solomon based on the data obtained in the H-1 heliac in 2002. In 2003-2004 H. Xia and M. Shats have shown that different waves in plasma turbulence exchange energy in the process of three-wave interactions such that the energy is transferred from smaller scales and higher frequencies towards larger scales and lower frequencies (Physics of Plasmas 11, (2004) 56). This result produced the first experimental evidence of the inverse energy cascade in plasma turbulence. It has been proposed that this process leads to accumulation of energy in large structures and may be responsible for the generation of zonal flows. The inverse energy cascade is the basis for the plasma turbulence self-organization.

![Figure 3: Flow chart of the energy flow within the turbulent spectrum. Inverse energy cascade leads to generation of large structures.](image-url)
III.2 Studies of Transport Barriers in the H-1 Heliac

Since the discovery of the low-to-high (L-H) confinement transitions in H-1 [M. Shats et al., Phys. Rev. Lett. 77 (1996) 4190], intensive experimental studies of this phenomenon have continued. Understanding the physics of improved confinement is crucial for achieving efficient modes of operation in future fusion reactors. The highlight of 2004 was the discovery of the transport barrier and the density pedestal, which form in the plasma during the L-H transition [H. Punzmann and M. Shats, Phys. Rev. Lett. 93 (2004) 125003]. The shape of the electron density profile in the vicinity of the transport barrier was found to be very similar to that in much larger tokamaks at higher magnetic fields. This has also been understood in the frame of a concept of dimensional similarity. In particular it has been shown that low-B large ion mass plasma in H-1 is dimensionally similar to plasma in high-magnetic-field experiments.

![Figure 4](image)

*Figure 4* Time evolution of the plasma density during confinement bifurcation from low to high mode. The higher order in the plasma correlates with the turbulence suppression.

Modifications to the electron density observed during L-H transitions are also remarkably similar to those observed in numerical simulations of the bi-stable sand-pile model. The formation of the transport barrier and of the characteristic “kink” in the density profile is observed in sand pile above a certain threshold in the particle deposition. This similarity points to the universal nature of the structural bifurcation in various physical systems [H. Punzmann and M. Shats, Complexity International (12) (2004) 83].

![Figure 5](image)

*Figure 5*: Left to right) Horst Punzmann, Dr. Michael Shats and Hua Xia presenting new results.
III.2 Toroidal Plasma Confinement

Magnetic Configuration Studies

In 2004, exploration of the vast configuration space of the H-1NF “flexible heliac” configuration was focussed on determining mode structure of the magneto-hydrodynamic (MHD) instabilities observed. The geometry of the magnetic confinement region can be varied in several dimensions, such as shape, rotational transform (“twist per turn”), and the depth of the minimum in magnetic field (“magnetic well”, related to stability).

Figure 6 The variation of rotational transform(lower), plasma density and instability frequency (upper, dots) with the ratio of currents in the helical and ring conductors. Significant rational surfaces at the edge are marked by dashed lines.

Studies of the confinement of hydrogen-helium plasmas heated with ion-cyclotron waves using very fine scale (steps < 0.5%) scans of the rotational transform show that the density confined in the heliac is very sensitive to the presence of surfaces with rational values of the rotational transform inside the plasma volume. When the rotational transform profile crosses multiple low order rational (e.g., 4/3) surfaces, the density drops to very low values, as is illustrated in Figure 6. Fluctuations in the magnetic field also show a fine structure that changes with rotational transform.

A second 20-coil external magnetic probe (Mirnov array) was installed to obtain toroidal mode numbers and improve poloidal mode data for these fluctuations. The 20 coil positions are shown in Figure 7, relative to the plasma. Near rational values of rotational transform of the form n/m, where n and m are integers, a predominance of poloidal mode numbers near the value of m is found. For
example, near a transform of 3/2, a poloidal mode number of 2 is clearly seen.

Mode numbers are determined either manually (Figure 8, by fitting phase variation against azimuthal angle, or by various numerical algorithms, such as counting the number of zeros around the periphery.

To understand the variation of plasma density with configuration, experiments were performed with a tubular limiter establishing different last closed flux surfaces. This is an alternative means of varying the rotational transform at the plasma edge, by moving the edge, instead of varying the rotational transform itself. The density variation behaviour was different, and three new small, sharp resonant features were found, at edge transform 4/3, 7/5 and 10/7. However there was no clear link between the broader features and the value of rotational transform at the plasma edge. The present understanding is that the main effect is due to the coincidence of a rational value of transform at a radial location where the spatial variation in rotational transform is low (low “shear”).

Initial configuration scans were performed with a different plasma heating source – electron cyclotron heating (ECH). The scans were not as detailed, but did not seem to have the fine scale variation with configuration as the RF produced plasma. Further work in this study awaits improvements in ECH power so that the plasma can be formed without any RF assistance.

**Data Mining**

It has become clear that the sheer volume of data is becoming unmanageable, and manual analysis such as in Figure 8 is too time consuming to apply to even any reasonable fraction of the data. A data mining project, funded by an ARC grant commencing this year will not only be able to deal with such quantities of data, but should extract much more information than possible with manual analysis. As part of this project, the summary database for facility operations will also be upgraded.

*D.G. Pretty, B.D. Blackwell, J.H. Harris*
III.3 H-1 Systems, Data and Automation

This year, the automation of H-1 was largely completed, and the new laboratories in the Weigold wing became operational. These replace the aging “Roundhouse” constructed for Sir Mark Oliphant in the 1950s. Facilities in these first-rate laboratories include multiple gas lines, closed circuit cooling water, vacuum exhaust and dry nitrogen. The six laboratories and the adjoining workshop will be used for preparation and calibration of instruments prior to installation on H-1, for spin-off developments and associated pursuits.

New systems include a directional gas injection system (DISH – section III) and an ECRH incident energy monitor, based on a sensitive bolometer mounted on the centre of the mirror the final mitre bend of the waveguide. Other gyrotron system improvements included realignment of the high power grooved circular waveguide, and commissioning of the full high voltage capacitor bank, allowing extension of pulses from 10ms to 40ms.

The “JavaScope” data viewer, from the Padua and MIT laboratories has been under further development by Drs. Blackwell and Gardner, mostly through senior student projects in “eScience”. In 2004, Mr. B. Dantuluri’s project was to add real time data capabilities, with a view to exploiting new high performance digitiser hardware for the PCI or CPCI bus (as used in personal computers). As we prepare for migration to the Linux operating system, the Java viewers are becoming an attractive option for everyday use. The increased CPU power makes up for the inefficiency of Java compared to native mode viewers, so that the extra features of the Java viewers can be exploited with very little loss in response time. The image capabilities of JavaScope are illustrated in Figure 14 in the Imaging section.

The fourth and final industrial programmable logic control controller (PLC) was installed for control of diagnostics. This essentially completes the automation of all power systems, cooling systems and the sequence that comprises a plasma pulse, reducing the manpower required to operate the H-1 facility.
and improving the quality of data by extensive logging of measurements. Importantly, automation enhances remote participation and collaboration by providing a more complete overview of operational parameters on line, and provides early warning of malfunctions.

Automation upgrades included the second phase of automation of the 200kW gyrotron electron cyclotron heating system including synchronization of the charging supply with H-1 firing, and precision monitoring and feedback control of the magnet currents. These measures greatly improve the long term stability of output power. Other improvements include online water quality monitors, vacuum pump, gate valve and cryopump monitors, and conversion to PLC control of the 62 point thermocouple temperature measurement system that monitors H-1 coil temperatures and cooling systems. The separation of machine control and diagnostics allow physicists to have free access to the diagnostics, without risk of compromising machine operation.

_B.D.Blackwell, G.C.Davis, R.J.Kimlin, C.M.Costa._

### III.4 Advanced Imaging and Inverse Methods

The AIIM group focuses on the development of advanced imaging tools spanning the optical to microwave regions of the spectrum focusing on applications in plasma science, but also in industry and other research fields. 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.

Among the highlights this year has been the successful deployment of the visible emission tomography system based on a 55 channel fibre coupled coherence imaging spectrometer demonstrated its full potential by imaging intensity, ion temperature and flow in an argon plasma. This work was undertaken by PhD student Mr Fenton Glass. Implementation of a comprehensive calibration procedure, based on in-situ miniature fluorescent sources allowed successful reconstruction of typical bean-shaped plasma images in a single shot. By accumulation of ~10 shots, an unusually shaped pair of magnetic islands was successfully reconstructed, corresponding very well to the shapes observed by vacuum magnetic surface mapping shown in Figure 11.

*Figure 11: Argon ion emission tomography showing good agreement with computed magnetic surfaces for an island pair near the n=3/m=2 resonance.*
Underpinning the 55-channel system are our patented high-throughput, 2-dimensional “coherence-imaging” systems. A number of these radically new optical measurement systems have now also been purchased by some of the world’s premier fusion laboratories. Related systems are also finding application in industrial process control (see Sec VII.1).

In recognition of this work, The Department of Education Science and Training awarded Dr Howard $191K in 2004 to undertake “Studies of high-temperature edge plasma confinement physics using new hyperspectral imaging systems”. This is a 3-year program involving researchers in the USA, Italy and Germany. It is centred on the application of coherence imaging systems for the study of high temperature plasma edge phenomena. Some preliminary results obtained using the CI camera on the WEGA stellarator in Germany are
shown in Figure 13. Recent success with the ARC LIEF scheme (led by Marcela Bilek, University of Sydney) will also see the installation of a CI system for measurements on the toroidal high current pulsed arc in the coming year.

This year has also seen the completion of PhD studies by Clive Michael. He has been using CI systems for detailed studies of the distribution function of hot argon ions in low field discharges in the H-1 heliac. Key results from his thesis have been submitted for publication in Plasma Physics. During his studies, Clive Michael discovered an unexpected significant non-thermal (hot) contribution to the ion velocity distribution function localised primarily to the plasma edge regions, suggesting that ions are directly heated in H-1 through stochastic interaction with the radio-frequency sheath attached to the heating-antenna. The measured distribution function and its close coupling with neutrals has been successfully explained in terms of ion-neutral interactions using a kinetic plasma model based on detailed collision cross-sections.

A modulated coherence imaging camera system has now been also installed on the H-1 heliac. Representative image data for a discharge heated by a gyrotron heating at the electron cyclotron resonance is shown in Figure 14. The figure also illustrates recent embellishments to the data-viewer software implemented by Dr Blackwell in collaboration with Italian colleagues.

Figure 14: Localised emission from DISH gas puffing during an electron cyclotron heating pulse. Image cross-sectional data is shown on the left, and plasma data on the right. This also illustrates the “JavaScope” data viewer being adopted as the standard data viewer for H-1NF.
**Interferometry and plasma fuelling in H-1**

The far-infrared (FIR) rapid-scan interferometer continues to operate reliably and has provided routine electron density profile information for a number of studies. Taken together with data from the CI spectrometer, we have established the need for a calibrated directional gas injection system for particle control. Great progress has been obtained this year by Mr. Scott Collis in designing and characterising the performance of the directional supersonic gas injector system for H-1. These results are being prepared for submission. We anticipate installing and testing the system in 2005.

PhD student Mr. David Oliver has also made great strides this year with the installation of a new electronically scanned millimetre-wave interferometer system based on our successful bid for ANU internal Major Equipment funding in 2003 for the purchase of a high-power millimetre-wave backward wave oscillator. The new system will allow the replacement of the rotating grating, giving higher sweep speeds and better signal to noise ratio.

![Figure 15: The new high power electronically-scanned backward wave oscillator to be used as source for the H-1](image)

**III.5 Wireless Communications**

Radio-frequency waves are used throughout PRL to produce and heat plasma. Our interest in rf technology has led to the development of a wireless communications research effort which is headed by Dr. Gerard Borg. The largest part of this program is the Bush Local Area Network (BushLAN) project, which is developing and demonstrating digital VHF (Very High Frequency) wireless technology for use in a novel scheme to provide long-distance (5-50 km) “last-mile” Internet connections to regional Australia on unused VHF TV channel frequencies.

Combining aspects of plasma physics and communications is the development of a broadband miniature plasma switch concept for use in mobile phones, in collaboration with Motorola-USA. Both these areas are described in more detail in section VII.
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 Australian Fusion Research Group Collaborations

Flinders University: Resistive Magnetohydrodynamic Stability of Stellarators

We have been able to utilise the completed 3D resistive magnetohydrodynamic (MHD) code SPECTOR-3D. A number of cases have been studied in detail, including Solov'ev equilibria, toroidal ripple situations (see below), Heliotron-E and LHD (Large Helical Device, Japan). The code has been checked using idealised cases against the standard benchmark equilibria of Nakamura et al. This code is designed to find the spectral properties (particularly for the unstable modes) of stellarator plasmas, systems which contain helically shaped plasmas of interest to the controlled nuclear fusion programme. The code consists of three sections:

1. The MHD equilibrium section. We have adapted the code VMEC, written by Dr Steve Hirshman, for our purposes and arranged the output in a suitable form for input into the mapping section.

2. The mapping section is based on Dr Tony Cooper's TERPSICHORE code and finds the Boozer coordinates for the plasma under consideration. Boozer coordinates are a specific coordinate system and are needed as for 3D plasmas they are the only helical coordinate system which are free of singularities. Thus they are necessary to integrate into the numerical scheme.

3. The stability section is the main part of SPECTOR-3D. It has been written to incorporate either inverse iteration (to find the dominant unstable mode) or to use the Jacobi-Davidson technique to find a range of spectral properties.

(B.F. McMillan (ANU), R.G. Storer (Flinders University))
University of Sydney: Laser Induced Fluorescence

This project received ARC funding for 2000-2003. The aim of the project was to develop techniques for measuring electric fields in plasmas using the laser excitation and fluorescence of metastable helium atoms in a pulsed helium beam. Work undertaken by the Sydney group with collaborators at Hiroshima University (Professors K. Takiyama and T. Oda), focussed on the development of a suitable metastable helium beam injector. A collision rate equation model for helium was used to model the experiment. Dr. Peter Feng joined the group for laser-induced fluorescence measurements of electric fields in the H-1NF plasma edge. His appointment was supported by a large ARC grant held jointly with the University of Sydney.

A highly directional injector, using a fast valve and a commercial flared conical skimmer was constructed and initial tests were very promising. The injector should also be a valuable localised helium source for helium neutral line ratio estimates of electron temperature and density. (B.W James, P. Feng, D. Andrczyk (Univ. Sydney) and J. Howard)

University of Canberra

A summer student (Kan-John) undertook a project on testing the existing electronics and designing an interchangeable foil version of the 16 channel soft X-ray system. The original system previously installed has been removed for repairs to the electronics, preparatory to being set up as a permanent multi-channel diagnostic to monitor X-ray emission from 0.5Tesla ECH and RF produced plasma. A measurable high-energy X-ray flux is produced even with modest RF powers at 0.5Tesla in hydrogen plasma. (P. Kan-John, B.D. Blackwell (ANU) and A.D. Cheetham, Univ. Canberra)
V FACILITY PROMOTION

In 2004, a number of promotional and awareness activities were undertaken by staff to promote the Facility. These include the publishing of recent research results in a number of refereed journals (see Section V.1) 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 VI). 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 (Section V.2).

These activities are summarised below

V.1 Publications

Book Chapters:


Refereed Journal Articles:


*Suppression of Large Edge-localized Modes in High-confinement DIII-D Plasmas with a Stochastic Magnetic Boundary


Fluctuations and Stability of Plasmas in the H-INF Heliac


Harris, J.H.

Small-to-midsized Stellarator Experiments: Topology, Confinement and Turbulence


McMillan, B.F., Dewar, R.J., Storer, R.G.,

A Comparison of Incompressible Limits for Resistive Plasmas

Physics and Controlled Fusion, 46, (2004) 1027-1038
Michael, C.A. and Howard, J.
Determination of Electron Temperature from Spectral Line Intensity Decay for Radiation Dominated Plasmas

Michael, C.A., Howard, J. and Blackwell, B.D.
Measurements and Modeling of Ion and Neutral Distribution Functions in a Partially Ionized Magnetically Confined Argon Plasma

Punzmann, H. and Shats, M.G.
Formation and Structure of Transport Barriers during Confinement Transitions in Toroidal Plasma

Punzmann H., Shats M.G.
Cellular automata model in particle transport studies in magnetized plasma,

Shats, M.G., Xia, H., Punzmann, H. and Solomon, W.M.
Spectral Energy Transfer, Generation of Zonal Flows and their Role in Confinement Transitions
Fusion Science and Technology 46 (2004) 279-87

Xia, H. and Shats, M.G.
Spectral Energy Transfer and Generation of Turbulent Structures in Toroidal Plasma

Configuration Effect on Energy Confinement and Local Transport in LHD and Contribution to the International Stellarator Database
Fusion Science and Technology 46 (2004) 82-90

V.2 Service to Outside Organisations
Dr B.D. Blackwell
Service to Stellarator Physics Advisory Committee, Princeton Plasma Physics Laboratory, Princeton, USA

Dr G.G. Borg
Editor, Czech Journal of Physics
Member, Foreign Relations Committee, ATSE
**VI COLLABORATION, EDUCATION AND TRAINING**

**VI.1 Collaborative Ventures**

**Dr B.D. Blackwell and Dr J. Howard**  
**Project:** Soft X-ray Measurements on H-1NF  
**Partner:** A/Professor A.D. Cheetham, University of Canberra

**Dr G.G. Borg and Professor J.H. Harris**  
**Project:** Plasma Antenna Concept Demonstrator  
**Partner:** Dr N.M. Martin, Defence, Science and Technology Organisation

**Project:** Infrastructure for Wireless Internet Technology Development for Rural Australia  
**Partners:** Ms H.M. Jones, A/Professor A.D. Cheetham and A/Professor J. Rayner, University of Canberra

**Dr G.G. Borg and Mr P. Linardakis**  
**Project:** Plasma Switches for Mobile Phones  
**Partner:** Dr R. Scheer, Motorola, USA

**Dr G.G. Borg and Mr I. McRobert**  
**Project:** VHF Wireless Technologies for Last-mile Internet Access in Regional Australia  
**Partners:** Standard Communications, Sydney; NJH Consulting, Newcastle

**Professor J.H. Harris and Mr B. Heslop**  
**Project:** VHF Wireless Technologies for Last-mile Internet Access in Regional Australia  
**Partner:** NJH Consulting, Newcastle

**Dr J. Howard**  
**Project:** Spectroscopic Studies of the Plasma Divertor in W7-AS  
**Partners:** Dr R. Konig and Mr J. Chung, Max Planck Institute for Plasma Physics, Germany

**Project:** Coherence Imaging on RFX Reversed Field Pinch
Partner: Dr M Valisa, Consorzio RFX, Padova, Italy

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

Project: Measurement of Electric Field in H-1NF Using Laser Induced Fluorescence Techniques
Partners: Professor B.W. James and Mr D. Andruczyk, University of Sydney

Dr M.G. Shats
Project: Electron Cyclotron Heating of Plasma in Stellarators
Partner: Dr K. Nagasaki, Kyoto University, Japan

Project: Confinement Studies in Stellarators
Partner: Professor K. Toi, National Institute for Fusion Science, Japan

Project: Turbulent Structures and Transport in Plasmas
Partners: Professor P.H. Diamond and Dr D. Rudakov, University of California, USA

VII CONTRIBUTION TO AUSTRALIAN INDUSTRY

VII.1 Optical Temperature Measurement

With an ACT Knowledge Fund grant of $40K obtained in conjunction with BHP Steel (now Bluescope), the AIIM group has developed an industrial radiation thermometer for the assessment of temperature of streams of molten steel and slag exiting a blast furnace. First trials with the split-image system were conducted at Bluescope Steel in Port Kembla. The system proved very successful, allowing measurements of molten steel temperature and its emissivity with new results relevant to steel making. A more sophisticated system is planned for future experiments that will allow simultaneous estimation of the emissivity colour slope – a potentially important correction when the surface emissivity varies with wavelength. Based on the trial results, Bluescope have indicated a willingness to proceed with further trials and/or participate in a linkage grant proposal.
Figure 16: False-colour split-image snapshot of the molten metal stream showing complementary polarizations. The diameter of the stream is approximately 10cm. The cooler blue-green region in the mid lower portion of the image represents molten material in the trough below the metal stream.

Figure 17: Top: A plot of ideal brightness-based temperature estimate (=1) and coherence-based temperature (red and green respectively) versus frame number averaged over the square region shown in Figure 16. Lower: The inferred emissivity.

VII.2 Radiofrequency Research
The BushLAN project investigates development of novel techniques for the transmission of high data rates at VHF. This work is aimed at the provision of a flexible long distance network for the provision of Internet services in regional Australia. The system has attracted attention locally and nationally up to federal government levels, and worldwide interest in
exploiting the vast amounts of bandwidth hitherto only available to television is fast gaining pace.

Motorola is sponsoring a PhD thesis to investigate the use of plasma as a switch. The aim of this work is to investigate plasma as a candidate for a switching medium between antennas in multi-band mobile phones. The research currently associated with each of these areas is described in more detail below.

**VII 2A  Novel Data Transmission Techniques**

In 2004, following tests in 2003, we began larger-scale deployment of a test network in the ACT and surrounding region. The BushLAN team obtained a three year licence to perform channel measurements and build test data links on 50 - 52 MHz and 56 - 63 MHz in the ACT region. Some basic hardware components have now been developed and a “radio” (means of encoding and decoding information, such as modulation and demodulation) now exists on which various physical layer platforms (means of transmission) can be implemented and tested.

![Figure 18: The system employed in tests in the ACT on show at the 2005 ACT Focus on Business Conference.](image_url)

Link trials and channel sounding measurements were performed using the TV spectrum. An example is the following evidence of multipath in line-of-sight (LOS) and non line-of-sight
locations. Figure 19 shows the channel impulse response exhibiting the worst case of observed multipath intersymbol-interference along with the discretised power delay profile, which can be interpreted as the main signal followed by ~9 delayed copies or echoes, largely decreasing in amplitude for longer delays.

![Figure 19: The system channel impulse response exhibiting the worst case of observed multipath intersymbol-interference (left) and the discretised power delay profile (right).](image)

Test links using this radio have been used to demonstrate data and voice over Internet (VoIP) communications. Some data now exists on link performance and clues are emerging about the challenges to be met by future physical layer platforms. Some interest has also been generated in possible applications of BushLAN to difficult real-world telecommunications problems.

**VII 2B   The Plasma Switch**

MOTOROLA Inc., USA has awarded the Plasma Research Laboratory a continuing contract totalling $49,500 to develop fast sub-miniature plasma switches for mobile phones. This grant is funding a PhD scholarship for Mr Peter Linardakis. He is performing a comparative investigation of plasma switches with the conventional technologies of PIN diodes and MEMS (micro-electromechanical systems) switches. Several prototype systems are currently being manufactured to test GHz range switching elements and Peter has begun to draft his thesis. An Australian firm can manufacture the tiny cell, but there are potentially significant problems in achieving a good vacuum seal to the device, exacerbated in prototype devices, to provide an adequately low base pressure.
VIII  STAFFING AND ADMINISTRATION

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

The management structure of the Facility is shown below. This structure involves three major organisations, namely the Department of Industry, Science and Research, (DISR), 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 Steering and Operations Committees, have direct impact on the Facility.

The role of AINSE through its Plasma Specialist Committee lies mainly in the facilitation and coordination of Australian collaborations and the allocation of travel funds in support of this. The AFRG has input at all levels as the collaborations with these external bodies is crucial to the objectives and success of the project.

The Steering Committee plans the various programs: construction, installation, commissioning and experiments. The Operations Committee is more or less the shop-floor organisation of the actual experimental work, and determines operational plans and schedules.

VIII-2  Membership of the H-1NF Board

As shown in the Table below, the Board is comprised almost entirely of ex officio members from institutions with an interest in the operation of the Facility. The present membership of the H-1NF Board includes representatives of Australian research institutions, government, industry, and overseas fusion research laboratories. The H-1NF Board meets two or three times per year at the ANU, and guides the operation of the Facility as a whole.

Members of the H-1NF Board are:

- **Chair ex officio**: Dr. J. Baker, MSc PhD Qld, OBE, FTSE
- **Scientific Secretary, AINSE (ex officio)**: Dr. D. Mather, BSc PhD UNSW, Dip Ed STC
- **AFRG Chair (ex officio)**: A/Prof. A D Cheetham, BSc PhD Flinders
AINSE Representative \textit{(ex officio)} \hspace{1cm} A/Prof. J.O’Connor, BSc PhD DSc ANU  
Univ. of Sydney Representative \textit{(ex officio)} \hspace{1cm} Prof. M. Bilek, BSc Syd, PhD Camb  
H-1NF Director \textit{(ex officio)} \hspace{1cm} Prof. J H Harris, MS MIT, PhD Wisc, FAPS, FAIP  
Overseas Fusion Reps. \hspace{1cm} Prof. A Iiyoshi  
Prof. Fujiwara  
Director, RSPhysSE, ANU \textit{(ex officio)} \hspace{1cm} Prof. J. Williams, BSc PhD NSW, FAA, FTSE, FAIP, FIEAust  
Senior Res. Admin. \hspace{1cm} Prof. L. Cram, BSc BE PhD Syd, FAIP, FRAS  
Industry Representative \hspace{1cm} Mr. A. Sproule, ME UT Syd, Grad Dip. OR NSW IT  
Member \hspace{1cm} Em. Prof. S. M. Hamberger, PhD DSc Lond, FAIP  
Member \hspace{1cm} Prof. Robin G. Storer, BSc, PhD Adelaide  
Member \hspace{1cm} Dr. R. Gammon, B.Tech PhD Brunel, FinstP, CPhys, MIEAust, CP Eng. FAIE, FAIM  
Minutes Secretary \hspace{1cm} Ms. H.P.Hawes, BA ANU  

\textbf{Figure 20:} H 1NF Board meeting, November 2004: (l-r) Prof. S. Buckman, Prof.J.H. Harris, Prof.R. Storer, Dr.I. Falconer (in attendance), Mr. N. Martin (in attendance), Prof. L. Cram, Dr. J. Baker, Ms. H. Hawes, Prof. J. O’Connor, Dr. R. Gammon, Prof. S. Hamberger, Mr. D. Wilson, DEST (in attendance)
ANU and AFRG Staff

Academic Staff
Prof. J.H. Harris (ANU), Director, H-1NF
Dr. B.D. Blackwell, (ANU), H-1NF Facility Manager
A/Prof. A.D. Cheetham, University of Canberra, Chairman, AFRG
Dr. J. Howard, (ANU) H-1NF Diagnostics Coordinator
Dr. G.G. Borg, (ANU)
A/Prof. R. Cross, University of Sydney
Prof. R.L. Dewar, (ANU)
Dr. H.J. Gardner, (ANU)
A/Prof. B. James, University of Sydney
Dr. M. Shats, (ANU)
Prof. R. Storer, Flinders University

Adjunct Fellows
Mr. Scott Collis, BSc Syd
Mr. Fenton Glass, BSc Qld
Mr. Clive Michael, BSc
Mr. Horst Punzmann, BSc Polytech Regensburg
Ms. Hua Xia, MSc Chongquing University, China

Technical Staff
Mr. G.C.J. Davies, Head Technical Officer

Mr. R.J. Kimlin
Mr. J. Wach
Mr. C. Costa

Administrative Staff
Ms. H.P. Hawes

Visiting Fellows
Prof. Joe Baker, MSc PhD Qld, OBE, FTSE
Prof. Marcela Bilek, BSc Syd, PhD Camb
A/Prof. Andrew Cheetham, BSc PhD Flinders, U Can
Prof. Lawrence Cram, BSc BE PhD Syd
Roger Gammon, BTech PhD Brunel, FInstP, CPhys, MIE Aust, CP Eng, FAIE, FAIM
Em. Prof. Sydney Hamberger, PhD DSc Lond, FAIP (Emeritus Professor)
Dennis Mather, BSc PhD UNSW, Dip Ed STC
Prof. John O’Connor, BSc PhD DSc ANU
Anthony Sproule, ME UT Syd, Grad Dip OR NSW IT
Prof. Robin G. Storer, BSc PhD Flinders
Keith Walshe, MSc Aston (Birmingham) PhD UMISt

Post-graduate Students
Mr Scott Collis, BSc Syd, ANUPS
Mr Fenton Glass, BSc Qld, ANUPS
Mr Ben Heslop, BE, ANUPS
Mr Santhosh Kumar, MSc Pune, ARCDisc
Mr Peter Linardakis, BE /BIT, APA
Mr Liviu Lungu, MSc Polytechnic University, Bucharest, SPIRT
Mr Ben McMillan, BSc Melb, APA (jointly with TP)
Mr Clive Michael, BSc, APA
Mr David Oliver, BSc, UWgong, APA
Mr David Pretty, BSc Melb, ANUPS
Mr Horst Punzmann, BSc Polytech Regensburg, ANUPS
Mr Jeta Vedi, BE BCom, APA
Ms Hua Xia, MSc Chongquing University, China, ANUPTS

Honours Students
Mr Roshan Banan Faculty of Engineering and IT, ANU
Mr Christopher Brooke Faculty of Engineering and IT, ANU
Mr Bhaskara Dantuluri Computer Sciences, ANU
Mr Stefan Foudoulas Faculty of Engineering and IT, ANU
Mr Rhys Goodwin Faculty of Engineering and IT, ANU
Mr Phillip Gowlett University of Sydney
Mr Mark Gwynneth Faculty of Engineering and IT, ANU
Mr Chris Hollins Faculty of Engineering and IT, ANU
Mr Robert May Faculty of Engineering and IT, ANU
Mr Eldad Ohanyon Faculty of Engineering and IT, ANU
Mr Andrew Vicquaret University of Sydney

Summer Scholars
Mr Christopher Brooke Australian National University
Mr Rhys Goodwin Australian National University
Mr Andrew Vicquaret University of Sydney

Outreach Activities
Founder's day presentation by Dr. Boyd Blackwell, on Automation of the H-1 National Facility

Many guided visits to H-1 including:
National Youth Science Forum January 2004
"Research Opportunities" August 2004
"Siemens Science Experience"

Undergraduate Teaching
Dr. Boyd Blackwell, Power Electronics ENGN4625/6625
Dr. G. Borg, 4th year Engineering
Prof. Jeffrey Harris, 3rd/4th year Plasma Physics
IX GRANTS AWARDED

Australian Research Council (ARC) Grants and Awards

ARC Discovery Project Grants
Professor J.H. Harris, Dr B.D. Blackwell, Dr J. Howard and Dr M.G. Shats
Localised Instabilities in Magnetically Confined Plasmas Heated by Radio Waves
2003 – 2005 $ 162,000

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 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

ARC Linkage – Infrastructure Equipment & Facilities
Externally led - Administered by University of Sydney
Professor M. Bilek, Professor J. Harris, Dr D. McKenzie, Dr B. James, Dr J. Howard, Dr B. Blackwell, Dr P. Pigram, Dr D. McCulloch, Professor R. Boswell, Dr C. Charles and Dr M. Shats
Interactive Network for Plasma and Surface Analysis
2004 Total ($ 726,000)
ANU $ 157,389

ARC Strategic Partnerships with Industry, Research and Training Scheme (SPIRT)
Professor J.H. Harris, Dr G.G. Borg, Dr N.M. Martin*, Dr D. Thorncraft and Mr L. Lungu
CEA Technologies and Neolite Neon
The Application of Plasma Antennas to Communications and Radar
2000 – 2003, extended to 2004 $ 63,240

DEST

Innovation Access Programs
Professor J. Harris and Dr M. Shats
Cross Platform Studies of Fusion Plasma Confinement in Tokamaks and Stellarators
June 2003 – April 2004 $ 50,600

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 $8,700,000

**Major Equipment Committee, ANU**

Externally led LIEF – University of Sydney
Professor J.H. Harris, Dr J. Howard, Dr B.D. Blackwell, Professor R.W. Boswell,
Dr C. Charles and Dr M.G. Shats (ANU Participants)
Interactive Network for Plasma Surface Analysis 2004 $72,000
X PROJECT PROGRESS VERSUS MILESTONES

The Table below lists the 2004 project progress against milestones from the MNRF contract. All but three (light highlights) are complete. Helium line ratio spectroscopy is being evaluated as an alternative to Thomson scattering. Operation at full field (1 Tesla) will be held back as pending results of electromagnetic force tests, and until results with the new ECH and ICH power sources have produced several publications, and until it can be decided if power line compensation should be implemented. The investigation of electromagnetic forces on the H-1 coil set, interrupted by the loss of a staff member, has been resumed as a 4th year engineering project for 2004-2005.

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Plan</th>
<th>Revised</th>
<th>Achieved</th>
<th>Status/Progress</th>
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<tbody>
<tr>
<td><strong>Magnet Power Supply</strong></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>
</tr>
<tr>
<td>1.0 Tesla</td>
<td>4-2000</td>
<td>7-2006</td>
<td></td>
<td>power supply to full current (11/99)</td>
</tr>
<tr>
<td><strong>ECH Plasma Heating</strong></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><strong>ICH Plasma Heating</strong></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>6-1998</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><strong>High Power Heating upgrade</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decide balance of ECH/ICH</td>
<td>6-1999</td>
<td>9-2005</td>
<td>depends on ECH/ICH above</td>
<td></td>
</tr>
<tr>
<td><strong>Diagnostics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<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>
</tr>
<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>
<td>4-1998</td>
<td>on time</td>
</tr>
<tr>
<td>2D tomographic density interferometer operational</td>
<td>4-1998</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiview Thomson scattering operational</td>
<td>9-1998</td>
<td>9-2006</td>
<td>May replace by Helium line ratio installed 9/1999</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>Complete, but offline for repairs</td>
<td></td>
</tr>
<tr>
<td>Multiview Soft X-ray diagnostic operational</td>
<td>3-1999</td>
<td>2002</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Data system</strong></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>
</tr>
</tbody>
</table>

Milestone completion status for H-1NF Development
XI FINANCIAL STATEMENTS

MNRF CASHFLOW REPORT
NATIONAL PLASMA FUSION RESEARCH FACILITY

Report for the quarter Ended: 31-Mar-04

| Name: Sandra Lenarcic |
| Position: Accountant, Special Purpose 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 2,104,011.95 A2 2,070,292.71</td>
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**RECEIPTS**

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<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>
<tr>
<td>Partner Contributions</td>
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<tr>
<td>Other Sources</td>
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<td>Interest</td>
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<td>TOTAL RECEIPTS</td>
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**EXPENDITURE**

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<th>Next Quarter</th>
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<td>Plasma Diagnostics</td>
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<td>Helicat Infrastructure</td>
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<td>Other Support Costs</td>
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<td>TOTAL EXPENDITURE</td>
<td>C1 49,498.78</td>
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**CASH BALANCE**

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<th>This Period</th>
<th>Next Quarter</th>
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</thead>
<tbody>
<tr>
<td>CASH BALANCE OF ACCOUNT</td>
<td>D1 2,070,292.71</td>
</tr>
</tbody>
</table>

S43085_Mar04.xlsScrnt
# MNRF CASHFLOW REPORT

**NATIONAL PLASMA FUSION RESEARCH FACILITY**

Report for the quarter Ended: 30-Jun-04

**Name:** Sandra Lenarcic  
**Position:** Accountant, Special Purposes Funds  
The Australian National University  

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<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 2,070,292.71</td>
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**RECEIPTS**  
This Period: 14,165.40  
Next Quarter: 0.00

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<td>Non-MNRF Program Funds</td>
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<td>Partner Contributions</td>
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<tr>
<td>Interest</td>
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<tr>
<td>TOTAL RECEIPTS</td>
<td>B1 14,165.40</td>
<td>B2 0.00</td>
</tr>
</tbody>
</table>

**EXPENDITURE**  
This Period: 137,679.70  
Next Quarter: 57,000.00

| Power Supply | 4,281.42 | 5,000.00 |
| Heating Systems | 9,144.90 | 5,000.00 |
| Plasma Diagnostics | 95,254.06 | 30,000.00 |
| Heliac Infrastructure | 19,579.71 | 10,000.00 |
| Other Support Costs | 8,819.61 | 7,000.00 |
| TOTAL EXPENDITURE | C1 137,679.70 | C2 57,000.00 |

**CASH BALANCE**  
CASH BALANCE OF ACCOUNT: 1,947,378.41  
Next Quarter: 1,890,378.41
**MNRF CASHFLOW REPORT**

**NATIONAL PLASMA FUSION RESEARCH FACILITY**

Report for the quarter Ended: **30-Sep-04**

**Name:** Sandra Lenarcic

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

---

### Unused Funds Available for this Period

| Cash Carried over from previous quarter | A1 1,947,378.41 | A2 1,869,394.03 |

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### RECEIPTS

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<th>Next Quarter</th>
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<td><strong>TOTAL RECEIPTS</strong></td>
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### EXPENDITURE

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<th>Next Quarter</th>
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<td>Heating Systems</td>
<td>4,620.13</td>
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<td>Plasma Diagnostics</td>
<td>42,352.37</td>
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<tr>
<td>Heliac Infrastructure</td>
<td>34,234.55</td>
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<tr>
<td>Other Support Costs</td>
<td>6,403.87</td>
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<tr>
<td><strong>TOTAL EXPENDITURE</strong></td>
<td>C1 91,495.98</td>
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### CASH BALANCE

<table>
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<th>This Period</th>
<th>Next Quarter</th>
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<tbody>
<tr>
<td>CASH BALANCE OF ACCOUNT</td>
<td>D1 1,869,394.03</td>
</tr>
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MNRF CASHFLOW REPORT
NATIONAL PLASMA FUSION RESEARCH FACILITY

Report for the quarter Ended: 31-Dec-04

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

<table>
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<tr>
<th>Unused Funds Available for this Period</th>
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<td>Cash Carried over from previous quarter</td>
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<td>Non-MNRF Program Funds</td>
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<td>Partner Contributions</td>
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<td>Other Sources</td>
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<th>EXPENDITURE</th>
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<th>Next Quarter</th>
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</thead>
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<td>Heating Systems</td>
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<td>3,000.00</td>
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<tr>
<td>Plasma Diagnostics</td>
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<td>30,000.00</td>
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<tr>
<td>Heliac Infrastructure</td>
<td>9,605.41</td>
<td>14,000.00</td>
</tr>
<tr>
<td>Other Support Costs</td>
<td>1,795.70</td>
<td>2,000.00</td>
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<tr>
<td>TOTAL EXPENDITURE</td>
<td>C1 52,401.90</td>
<td>C2 53,000.00</td>
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<table>
<thead>
<tr>
<th>CASH BALANCE</th>
<th>This Period</th>
<th>Next Quarter</th>
</tr>
</thead>
<tbody>
<tr>
<td>CASH BALANCE OF ACCOUNT</td>
<td>D1 1,834,060.91</td>
<td>D2 1,781,060.91</td>
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</table>
## List of Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
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<tbody>
<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>FEIT</td>
<td>Faculty of Engineering and Information Technology</td>
</tr>
<tr>
<td>HARE</td>
<td>Helicon Activated Reactive Etching</td>
</tr>
<tr>
<td>H-1NF</td>
<td>Heliac-1 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>
</tr>
<tr>
<td>SOFT</td>
<td>Spread-Spectrum Optical Fourier Transform</td>
</tr>
<tr>
<td>SPIRT</td>
<td>Strategic Partnerships with Industry - Research and Training Scheme</td>
</tr>
<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>
</tr>
<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>
</tr>
<tr>
<td>WKB</td>
<td>Wentzel-Kramers-Brillouin</td>
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</table>