Fusion Research: Australian Connections, Past and Future

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Three recent articles in Nature: Physics, on plasma physics issues relevant to the ITER fusion power experiment*[see inset], have Australian connections. Although Australia does not yet have any formal involvement with what is claimed to be the world's largest truly international scientific experiment, this connection is not surprising in view of the long and distinguished history of Australian contributions to fusion research. Beginning with the discovery of nuclear fusion, and the "triton" (tritium or 3H ion) by Sir Mark Oliphant and Lord Rutherford in 1933, Australians have made notable experimental and theoretical contributions both at home and in various overseas laboratories. Australia can claim the first tokamak in the western world, the Liley Torus. The "Rotamak", a spherical device, was invented by Professor I. Jones of Flinders University, and later at ANSTO, produced the world's first demonstration of a spherical torus configuration.

Recently the focus of Australian toroidal plasma confinement research has been the H-1 National Plasma Fusion Research Facility, based on the Heliac (helical axis) plasma configuration, a toroidal plasma of the stellarator type, first demonstrated in Australia. H-1 allows basic research into advanced plasma shapes and provides a test-bed for the development of advanced plasma measurement systems.

At a time when Australians are discussing possible participation in the international plasma fusion experiment ITER (see insert on the Australian ITER forum workshop October 11-13), it is appropriate to review past Australian contributions to fusion research, present research directions, and future opportunities, including potential involvement in the ITER.

Thermonuclear Ringtones and Fuzzy Boundaries

In the May issue of Nature: Physics, the article "Thermonuclear Ringtones[1]" describes recent studies of the time evolution of the spectrum of Alfvén Eigenmodes in tokamaks, a key physics issue for the upcoming ITER experimental plasma fusion reactor. The experiments on the DIII-D plasma device in California reported[2] in Physical Review Letters by Dr. Raffi Nazikian and a team of researchers, demonstrate a new aspect of this phenomenon, the excitation of the instability by thermal particle distributions (in the presence of steep temperature gradients). Dr. Nazikian, a Principal Research Physicist at Princeton Plasma Physics Laboratory, and Head, DIII-D Collaboration Division of the PPPL, graduated from the University of Melbourne, and studied plasma scintillations on the LT4 tokamak at the Australian National University for his PhD thesis.

The articles address a critical issue for fusion reactors: the effect of the energetic fusion-generated alpha particles on the stability of the hot plasma. If the velocity of the alphas approaches the Alfvén velocity, they can drive an instability at the Alfvén resonant frequency, typically in the supersonic to sub-Megahertz range. As burning fusion plasma relies on the power from fusion alphas for heating, the effect of this instability on plasma confinement in general, and the confinement of those energetic alphas in particular, is crucial, and has been designated a priority area (Topical Group) under the International Tokamak Physics Activity(ITPA). In addition to the coincidence of the Alfvén phase velocity with the energetic alpha velocity, gaps or stationary points in the Alfvén dispersion relation can impede propagation of energy away from the source, allowing the oscillation to grow to large amplitude. While this has been an active area of investigation for over a decade, this report is the first evidence of the instability being driven by resonant particles in a thermal distribution function. The authors suggested that steep temperature gradients near a thermal barrier were an important factor in this case. A related phenomenon observed on the H-1 National Facility in Canberra will be described below (*sonogram in Fig 2). Finally, why "ringtones"? The data published in Nature showed a sonogram ("voiceprint") made up of a cluster of frequencies resembling a touch tone dial signal, instead of the single frequency shown in Figure 2.

Two articles in a later issue of Nature: Physics[3], report aspects of an advance in plasma physics that may provide a solution to the crucial technological problem of extreme power density as the edge of a plasma fusion reactor such as ITER. In tokamak plasma, edge localised modes (ELMs) of instability release energy in powerful bursts, which could create intolerable thermal stresses in the plasma facing components, especially the divertor plates, and disrupt radio frequency plasma heating systems. By deliberately introducing a small chaotic region of magnetic field at the edge of the DIII-D plasma, a team of researchers[4] including ANU plasma physicists Prof. Jeffrey Harris and David Pretty showed that the large ELM spikes were controlled or suppressed. This technique was successful on a range of plasma configurations, including those which were designed to imitate plasma in the next step international fusion reactor prototype, ITER. Although the results bode well for that experiment, a number of physics questions have been raised in relation to stochastic transport theory when applied to these "collisionless" highly rotation "pedestal" (edge) plasmas.

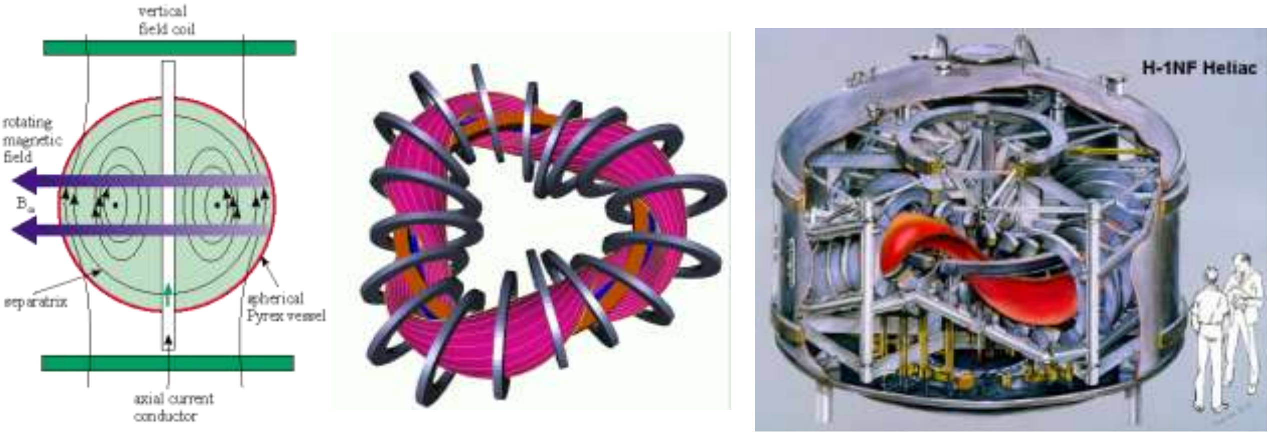
A brief history of Australian fusion research

The Australian connections in fusion research have a distinguished history. In 1933 [5], while investigating the interactions between positive ion beams and various solids at the Cavendish laboratory, Cambridge, Sir Mark Oliphant and Lord Rutherford discovered the heavy hydrogen isotope tritium, and the ^{3}Helium isotope, by bombarding deuterated compounds with deuterons of energies up to 400kV. Energy balance analysis corroborated their postulate of a nuclear fusion process, and from stopping distances, energies of the emitted neutron and He^{3} ion were estimated at 2 and 0.7MeV respectively, within 20% of the presently accepted values. Oliphant was an early advocate of fusion energy.

In 1958, under Oliphant, Hilary Morton started research into plasma physics at the Australian National University. In 1963, Bruce Liley, a plasma theorist born in New Zealand, joined the group and began the construction of LT-1, which he described as a "slow toroidal theta-z pinch". This turned out to be the first tokamak outside of Russia. Initially the most successful plasma confinement device, the "tokamak" was a doughnut-shaped ring of plasma confined by a toroidal magnetic field and a large current flowing around the torus. This current also heated the plasma, but was the source of serious "periodic disruptive" instabilities. The Russian inventors concentrated on stabilising these instabilities and stunned the international community by demonstrating a hot, well confined plasma in the T-3 tokamak in 1968.

The Australian group realised that they had a very interesting plasma device and focussed on studying the instabilities in detail; they produced important insights into the phenomenon, for example, that a disruption rapidly redistributed the current throughout the plasma column [6].

Sizeable plasma research groups were founded at the University of Sydney in 1961 by C.N. Watson-Munro and later (1964) at Flinders University by M. Brennan, focussing on plasma diagnostics and wave propagation in a variety of linear geometries, with shock wave, radiofrequency and axial current heating. These groups established a strong tradition of research in Alfvén wave phenomena[7], *which later became the focus of the Sydney TORTUS tokamak, and which continues in the work on Alfvén Instabilities described later in this paper. Later, at Princeton University, R.L. Dewar[8] discovered a modification to the dispersion relation, caused by mode coupling, that produces some of the key features of Alfvén eigenmodes.



a) b) c)

Figure 1 a) The Rotamak spherical torus showing indicative magnetic field lines b) The H-1 heliac. The copper coloured circular conductor creates twist in the confining field lines. Only 18 of the 36 toroidal field coils are shown (grey) c) Cutaway view of the complete heliac, the centrepiece of the H-1NF.

I. Jones[9], at Flinders University invented and developed the "Rotamak" configuration, an approximately spherical plasma configuration created by a rotating r.f. magnetic field in the sub-Megahertz range. This led to the world's first demonstration of a "spherical torus" configuration[10] in collaboration with the plasma group at the Australian Nuclear Science and Technology Organisation. This configuration is a compact form of the tokamak which is expected to be more efficient as a fusion reactor, with a larger plasma volume for a given device size. Along with the stellarator, this configuration is a contender for the experiment that will succeed ITER.

Conceived by an international team, the first heliac confinement device, "SHEILA" was built at the Australian National University in 1985 [11], followed in 1992[12] by the H-1 heliac, the first heliac of sufficient size to approach "hot plasma" conditions (neutral particles are ionised before reaching the core, and charged particles sample the full extent of the magnetic geometry before experiencing a collision). The heliac is a toroidal confinement geometry defined by a magnetic field generated entirely by currents in external conductors. In particular, the twist of the magnetic field lines is generated by current in a central circular conductor instead of the current in the tokamak plasma. This avoids the instabilities inherent to the internal plasma current of the tokamak, and obviates the need for a transformer to drive this current, which limits the tokamak to pulsed operation. The heliac is distinguished from other stellarators by its helical plasma axis; both the magnetic field lines, and the plasma itself are highly twisted. This combination of twists increases the rotational transform (twist per turn) to 1 – 2, well above that attained in the tokamak (1/3 – 1/2), and provides stability at higher plasma pressure (β). Furthermore, H-1 is a "flexible heliac", by virtue of a helical control winding wrapped around the circular conductor, with the same helicity as the plasma. Relatively small currents (~10%) in this winding allow control of the plasma shape and vary the rotational transform from 0.6 to 1.5.

Australian Research in Fusion Science: Plasma and Atomic Physics and Materials Research

Present day research related to the development of fusion power is spread over a wide range of topics and locations in Australia. The plasma physics component of this is part of a larger research community in basic and applied plasma physics, but in this article, we will focus on the research potentially relevant to plasma fusion reactors, and in the near term, the ITER experiment. Some specific examples are given which are directly applicable to ITER.

The present focus of Australian toroidal plasma confinement research is the ***H-1 National Plasma Fusion Research Facility***, based on the H-1 Heliac device, which was upgraded in the first round of the Major National Research Facilities funding. Although not intended (and not large enough) to produce fusion, H-1NF allows basic research into advanced plasma shapes for the generation of devices following the ITER tokamak. The facility consists of the H-1 heliac, two high frequency heating sources, and a 12MW dual precision magnet power supply. The H-1 plasma has an average minor radius up to 0.2m, a major radius of 1m, in a $33m^3$ vacuum tank, containing 39 coils designed to produce magnetic fields up to 1 tesla. Typical operation is in H, He or D at 0.5 tesla, where the electron cyclotron second harmonic frequency matches the 28Ghz, 200kW microwave heating source, or at low fields in radio frequency heated (7MHz, 100kW) Argon plasma, where a higher pulse repetition rate is possible, and Langmuir probes may be used.

The flexible magnetic geometry of H-1NF can be summarised by three quantities, the rotational transform (ι) or twist per turn of the magnetic field lines, the spatial derivative of this ("shear") and magnetic well, a measure of the decrease in average magnetic field in the centre of the plasma. These quantities are central to the stability of magnetically confined plasma, and their variation can be used to test fundamental stability theories over a much wider range of parameters than is possible in highly optimised machines.

In addition to providing a "test-bed" for plasma diagnostics, and plasma conditions similar to edge plasma in a reactor, H-1 allows investigation of several fusion plasma phenomena on a smaller scale. Originally, transitions to a "high confinement" mode were reported by Shats[13], that reproduced most of the characteristics of those found in the largest machines, but were more conveniently accessed, and allowed detailed examination of the physics involved. The present design for ITER relies on a high confinement mode for successful operation of in a "burning plasma" mode.

Phenomena closely related to the fast particle driven Alfvén eigenmodes described earlier are observed in H-1. The spectra shown in Figure 2 are less complex than those of Nazikian et al., but using H-1 Facility we are able to explore a wider range of parameters, with more detailed measurements than the large scale plasma experiments. For example, the absence of significant plasma current, and the ability to map the magnetic configuration in vacuum means that the rotational transform is much more precisely known than in a tokamak such as ITER. This, in conjunction with the world's only fully tomographic 2-d imaging plasma interferometer for plasma density measurement [14], allows unequalled precision in the prediction of the Alfvén dispersion relation which is at the heart of these instabilities. Another advantage of the configurational flexibility in H-1NF is access to the low shear or reversed shear configurations of next-generation fusion reactors such as advanced tokamaks or stellarators.

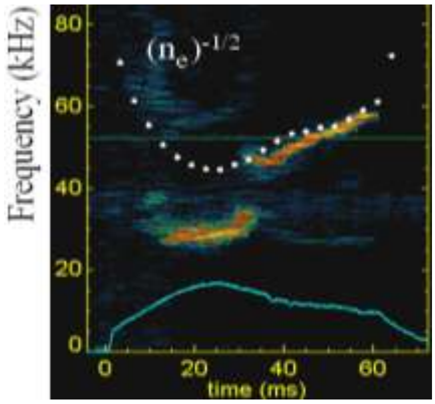


Figure 2 Frequency-time diagram of magnetic fluctuations in H-1NF showing the plasma density n_e in blue, and Alfvénic scaling with $1/\sqrt{n_e}$ (white).

In addition to their main lines of research in plasma processing, the development of materials for fuel cells, and the helicon plasma thruster, the Space Plasma Power and Propulsion (SP3) group in the RSPhysSE at ANU carries out research into the physics of high beta plasmas and the behaviour of instabilities both parametric and pressure driven. Primarily the research is experiment driven supported by analytical modelling and a variety of PIC and hybrid computer simulations. Initial visits to American and German Laboratories confirm that SP3 has the opportunity and the plasma systems to take part in programs that are related to fusion and in particular ITER. Collaborative programs have been initiated with W7X in Greifswald and the Ruhr University in Bochum. The research would be greatly aided by funding for bilateral exchange of staff between these institutions and appropriate funding of travel and bench fees required for new experiments.

Plasma Theory

Australia can make a low-cost, high-impact contribution to ITER science in theory and modelling. Areas of active research include energetic particle mode physics (e.g. Alfvén waves), multiple-fluid modelling, 3D MHD equilibrium and stability studies, and integrated-modelling. The plasma theory group at ANU (Prof. Robert Dewar, Dr. Rowena Ball, Dr. Matthew Hole and Dr. Ruysuke Numata) is also very active in turbulence studies, and dynamical systems modelling. These research efforts aim to understand the causes and conditions of turbulence suppression (which leads to higher performance), and develop dynamical system models to describe their behaviour.

Fusion plasmas are complex and turbulent environments. In a hot, magnetically confined plasma, free energy is readily available to small wavelength instabilities. At saturation, these instabilities can give rise to turbulent plasma mixing, reducing plasma confinement. Research by Dewar, Numata and Ball seeks to understand the dynamics of turbulence, and explore conditions under which turbulence can be suppressed such as the formation of zonal flow patterns. This fundamental research offers the promise of developing improved confinement configurations on ITER.

Magneto-hydrodynamic (MHD) theory treats plasma as a highly conducting fluid, and the "ideal" approximation (zero resistivity) has been remarkably successful in describing the equilibrium and stability of various plasma configurations. However according to ideal MHD theory, plasma configurations which do not have an ignorable coordinate (3D plasmas) should not, in general, be able to support a continuous nonzero pressure gradient. In such plasmas theory predicts the pressure gradient to be zero in chaotic magnetic field regions, which arise due to the non-integrability of the magnetic field, viewed as a Hamiltonian dynamical system. In practice however, 3D plasmas, such as stellarators and weakly asymmetric tokamaks exhibit good performance, in which the observed pressure gradient appears to continuous and nonzero. The purpose of this research is overcome a long-standing problem in ideal MHD, by the development of a stepped pressure-profile model of 3D plasma configurations. Practical outcomes include better tools for modelling non axisymmetric toroidal systems. [15]

Integrated Plasma Modelling

Fusion plasmas are far from thermal equilibrium. They are driven systems, with multiple energy reservoirs and sinks, including fusion-born alpha particles, collisional heating (e.g. neutral beams), wave-particle resonant heating, magnetic reconnection, and cold gas puff injection. Hole et al. has developed an energetically resolved fluid model, which treats the different energetic populations as different fluids. Steady-state model solutions provide a self-consistent description of the plasma, providing energy resolved equilibria in realistic geometry, and form a basis for modelling the excitation of Alfvén eigenmodes described at the beginning of this article.

Significant improvements in diagnostics and numerical models have led to the need for more complete data integration algorithms and approaches. Folding data together from thousands of diagnostics as input into numerical reconstruction codes is a heavily over-constrained problem. Applying these models to well diagnosed plasma such as the future ITER experiment normally means folding together highest-confidence data, and optimizing the data set to minimise a global measure of fit.

Plasma Measurement Systems

Plasma measurement systems under development by the Australian National University and the University of Sydney will allow improved monitoring of the state of the plasma. Supersonic helium beam probes provide localized sites of helium neutral and ion emission, which allows spatially resolved measurement of plasma density and temperature at the ITER plasma edge. The extension of the system to metastable He ions will enable electric fields to be included in the measurements.

New ***coherence interferometry*** techniques provide measurements of the distribution of ion velocities and temperatures. Research on the tomography of vector fields, especially in relation to Doppler spectroscopy of plasma flow fields[16] in the NF national fusion plasma research facility at ANU has led to the development of novel optical "coherence imaging" systems (CIS). This work, undertaken by John Howard and his group, at ANU [17], has spawned several patents, and resulting in installation of CIS optical plasma diagnostic systems in fusion labs in the US, Korea, Germany and Italy.

The CIS technology, which is based on the use of spatial and/or temporal multiplex techniques to image the optical coherence of a given spectral scene, has also led to the development of "coherence pyrometry" systems for measuring temperature, emissivity and emissivity-slope in thermography applications. A 4-quadrant system has been recently trialled successfully under contract to Bluescope Steel to monitor the molten iron stream at their blast furnaces in Wollongong.

Based on polarizing interferometric techniques, CIS offers the important advantages of high light throughput and the capacity to spectrally image simple two-dimensional scenes. A variant of this technology[18] is presently being developed under contract for trial on the laser Thomson scattering system at the JT-60U tokamak in Japan – the world's second largest fusion device. Successful operation will almost certainly see this technology adopted for the Japanese laser Thomson scattering systems on the ITER tokamak.

Plasma Wall Interaction

Plasma ions and electrons have kinetic energies to over 50keV. At the low energy end (~1keV) this covers the energy range which is a maximum for sputtering erosion of the surface and over the whole energy range there is the potential to modify the surface and near surface composition. The plasma particles interacting with the surface will lose energy (become colder) and have a significant chance of being neutralised which eliminates the capacity to control them with magnetic fields. This form of interaction has been an ongoing research topic at the University of Newcastle, where such low and medium energy ions have been used routinely for surface analysis and modification. Currently research is underway on the effect of low energy bombardment of TiSiC alloys to ascertain what enrichment and sputtering processes dominate.

An understanding of electron-atom and atom-atom collisions is particularly important at the plasma edge, and in the magnetic divertor which controls impurity and heat flux. This is an active area of research for Prof. Igor Bray and Dr. Andris Stelbovics of Murdoch University. They have ongoing collaborative projects with The International Atomic Energy Agency to provide electron impact data for the light atomic and ionic species in fusion plasmas, as well as alkali atoms injected into the plasmas for diagnostic purposes.

Dusty Plasma

Charged dust particles form an additional plasma species, and add fascinating complexity, such as quasi-crystalline ordered states, and an electronic charge that depends on frequency. Recently, there has been a significant increase in interest by the fusion community in the role of dust in fusion plasmas. It is well known that fusion devices are rather "dusty" in the periphery regions; however, the impact of dust on the performance of fusion plasmas is not clear at the moment. The dust can affect the transport and re-distribution of eroded material of first wall components as well as plasma auxiliary heating. As we advance to high-power, burning plasma experiments such as ITER, it becomes more crucial to understand the physics of radioactive, mobile, and, therefore, potentially hazardous substances like dust. Research in dusty plasmas performed in the Complex Systems Group (S. Vladimirov) which includes theoretical/computational/modelling studies as well as dusty plasma experiments at the Complex Plasma Laboratory (A. Samarian) can be related to priority research areas. These are designated in the International Tokamak Physics Activity (ITPA) High Priority Physics Research Areas for the ITER Physics Design, in the areas of Internal Transport Barrier properties, pedestal physics and the scrape-off layer and divertor area. The world-class quality of dusty plasma research at the Complex plasma Group of the University of Sydney is exemplified by recent invitation of Prof. S. V. Vladimirov to the Japanese National Institute for Fusion Science as a Visiting Professor in January-March, 2006.

Materials Development and Testing

ITER will place extreme demands on materials in that the first wall will face a high temperature plasma, high heat loads, radiation damage from 14MeV neutrons and potential neutron activation. As well, there has to be the capacity to remove heat from the reaction products, minimize plasma contamination from heavy elements, maintain structural integrity and allow lithium to be exposed to the maximum neutron flux to allow the production of tritium as a fuel. No one material can meet all these demands so there will be different materials at various stages through the process. Australia has a wealth of experience in materials synthesis and characterization which can benefit the development of new alloys with extreme properties.

One area of particular interest and current research is the production and characterization of MAX phase alloys which combine the electrical properties of metals with the oxidation and thermal resistance of ceramics. A variety of production process options are available including Self-propagating High temperature Synthesis, plasma deposition and Hot Isostatic Pressing. This work involves collaborative research by ANSTO and the Universities of Sydney and Newcastle, with additional research activities at UTS and UNSW. Advanced materials growth and growth facilities have been developed at these sites to explore new materials combinations expanding the capability envelope of materials. World-class facilities for the sophisticated probes (electron, x-ray, neutron) required for the micro-structural analyses of these advanced materials are readily available at the Australian Key Centre for Microscopy and Microanalysis (electron), the Australian Synchrotron (x-ray) and ANSTO-OPAL (neutron).

The expertise and facilities developed at the University of Wollongong over the past 30 years in physical metallurgy, high temperature materials, characterisation and welding research is of direct relevance to the challenging materials research problems associated with fusion energy systems. The key aspects of materials performance of structural alloys used for the construction and maintenance of fusion reactors include weldability, resistance to high heat flux and radiation, the embrittling effects of H and He transmutation elements and the high thermomechanical loads that produce significant stresses and time-dependant strains. Further, a key factor that has not received sufficient attention to date is the consideration of weld regions in fabricated components, as these are often more structurally heterogeneous and more likely to contain detrimental transformation products or structural defects. This range of expertise represents a invaluable asset to an Australian fusion materials initiative.

Relatively low level fusion neutron fields have the potential for causing defects in semiconductor electronics that will be used for a wide range of diagnostics and monitoring on ITER. Moreover, dosimetery and other radiation health effect issues need to be considered in this environment. Australia has the local expertise for producing small scale fusion neutron sources, based on the electrostatic confinement of energetic plasma, which will enable these studies to be carried out. A prototype device, using hydrogen plasma has been demonstrated by Dr. Joe Khachan of the School of Physics, University of Sydney, and an improved deuterium device is under construction. In such a device electrostatic confinement results when a deep electrostatic potential is created in a plasma. Ions that are accelerated and trapped by the potential have a much increased chance of fusion events taking place. It has been shown [19] that with a modest power input (i.e. 5 - 10 kW, in D-D plasma) it is possible to produce 10^8 2.45 MeV neutrons per second operating in the electrostatic confinement mode. Consequently, it is also possible to produce 14 MeV neutrons at a factor of a hundred higher (i.e. 10^{10} neutrons/second) in a D-T plasma [20]. In addition, these devices are on a scale such that they can be built to a desktop size with matching small scale costs.

Prospects for a stellarator fusion reactor

One may ask, given the high level of international interest in the ITER tokamak, and the potential for Australian involvement, "why is the H-1 Facility a stellarator?" The H-1NF configuration was chosen with an eye to the future: the step beyond ITER. Present performance parameters of tokamaks significantly exceed those achieved so far in stellarators, so ITER will be a tokamak. However the fundamental advantage of the stellarator configuration – that it does not require a large current flowing in the plasma – combined with highly encouraging recent results has led some to propose that the subsequent device, the "DEMO" reactor, be an advanced stellarator.

The superconducting stellarator "LHD" in Japan has already achieved plasma durations of more than 30 minutes. In the last decade, significant breakthroughs were achieved in the computer optimisation of magnetic field coils to achieve "quasi-symmetry" [21], one of several symmetries in magnetic coordinate space, even though in real space, the shape is far from symmetric. Recent stellarator reactor designs are competitive in size and performance with advanced and spherical tokamaks. The next generation of superconducting and highly optimised stellarators will hopefully confirm, on a larger scale, the freedom from disruption and the promising results on confinement and stability recently observed in Germany and Japan[22]; the high density high confinement mode (HDH[23]) exceeded operational limits of tokamaks both in rotational transform and plasma density. If so, we may well see a "DEMO" reactor in the form of a highly optimised stellarator.

References

[1] S.C. Cowley, *Nature Physics* **2**, 299 - 300 (May 2006)
[2] R. Nazikian et al. *Phys. Rev. Lett*. **96**, 105006 (2006).
[3] T. E. Evans et al. Nature Phys. **2**, 419–423 (June 2006), A. Loarte et al., 369 - 370 ibid.
[4] T. E. Evans et al. Nucl. Fusion **45**, 595-607 (2005).
[5] M.L.E. Oliphant, P. Harteck and Lord Rutherford, *Pro., Royal Soc. Lond. A*, **144**, 692 (1934)
[6] Dewar R.L. et al., 'Bruce Liley – Obituary' http://phys.waikato.ac.nz/staff/bruce_liley/liley_obit.pdf

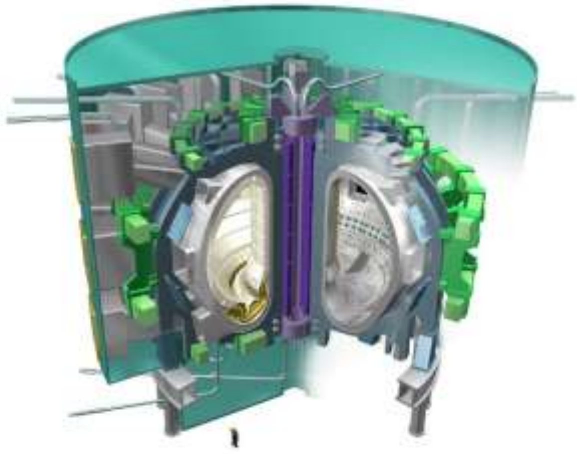
[7] R. Cross, 'An introduction to Alfvén waves', Adam Hilger, Bristol and Philadelphia, 1988, N.F. Cramer, 'The physics of Alfvén waves', Wiley-VCH, Berlin, (2001)
[8] R.L. Dewar *et al.*, *Phys. Fluids,* **17**, 930 (1974)
[9] I.R. Jones Flinders University, Adelaide, Report No. FUPH-R-151, NTIS-PB85-133858, (1979).
[10] G.A. Collins et al., *Nucl. Fusion*. **28**, 255 (1988)
[11] B.D. Blackwell, S.M. Hamberger, L.E. Sharp and X-H Shi, *Nucl. Fusion* **25**, 1485 (1985)
[12] S.M. Hamberger, B.D. Blackwell, L.E. Sharp and D.B. Shenton, *Fusion Technol*. **17**, 123 (1990)
[13] M.G. Shats, D.L. Rudakov, B.D. Blackwell, G.G. Borg, Dewar, R.L., S. M. Hamberger, Howard, J. and Sharp, L.E., *Phys. Rev. Lett*. **77,** 4190-3 (1996)
[14] John Howard and David Oliver, accepted, Applied Optics (2006)
[15] M.J. Hole, S. R. Hudson, R.L. Dewar, "Stepped pressure profile equilibria in cylindrical plasmas via partial Taylor relaxation", **Journal of Plasma Physics*, to appear (2006).
[16] J. Howard Vector, *Plasma Phys. Control. Fusion,* **38**, 489 (1996)
[17] J. Howard, High-speed high-resolution plasma spectroscopy using spatial-multiplex coherence imaging techniques, accepted, *Rev Sci. Instrum*., (2006)
[18] J. Howard, *Plasma Phys. Control. Fusion,* **48**, 777 (2006)
[19] A.L. Wehmeyer, R.F. Radel, G.L. Kulcinski, *Fusion Science and Technology*, 47, 1260 (2005)
[20] G.H. Miley, J. Sved, *Applied Radiation and Isotopes*, 48, 1557 (1997)
[21] J. Nuhrenberg, R. Zille, *Phys. Lett.* A129, 113 (1988)
[22] N. Ohyabu et al, *Phys. Rev. Lett*. 97, 055002 (2006)
[23] McCormick K., Grigull P., Burhenn R., Brakel R, *Phys. Rev. Lett*. 89, art. 015001 (2002)
*Several of the topics presented here will be covered in more detail in papers at the Pacific Basin Nuclear Conference in Sydney 15-20th October.

[Side box briefly describing ITER and the Aust. ITER forum workshop]

ITER and the Workshop: "Towards an Australian Involvement in ITER" – October 12-13
ITER is an international fusion science experiment to demonstrate a self-sustaining deuterium-tritium fusion reaction on a scale suitable for the generation of clean, safe, low emission energy. The ITER partners comprise the European Union (represented by Euratom, including Switzerland), Japan, the Russian Federation, the United States of America, the People's Republic of China, the Republic of Korea and India. In addition the broader ITER project aims to realize the technologies essential to a functioning reactor, including components capable of withstanding high neutron and heat-flux.

A group of over one hundred scientists and engineers have formed the Australian ITER Forum, which aims to develop the case for an Australian role in the ITER project, both by participation, and the formation of an International Centre of Research Excellence in Fusion Related Research. With Federal Government support, the Australian ITER Forum has scheduled a workshop for October 12-13, "Towards an Australian involvement in ITER" www.ainse.edu.au/fusion. It will bring together the research community, industry, government, and the ITER partners to discuss a possible role for Australia, building on its past accomplishments, to participate in the pioneering demonstration of the ultimate clean, sustainable base load energy source.

I suggest one of these two sample pictures. Both are available in high resolution jpeg, and may be used with the acknowledgement in the caption(published with permission of ITER)



Inside the ITER cryostat showing magnets and vacuum vessel with protective tiles and divertor added to the left side (published with permission of ITER)

High resolution picture may be downloaded from http://www.iter.org/pics/verdult/REACTOR1.jpg
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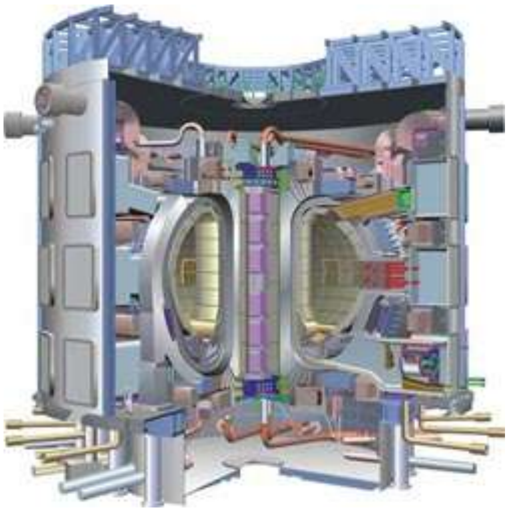

Cutaway view of cryostat showing magnets and vacuum vessel (published with permission of ITER)
High resolution picture may be downloaded from http://www.iter.org/pics/ITER_col.jpg