The Australian Plasma Fusion Research Facility is designed to perform research into the basic properties of magnetically confined, high-temperature plasma as the Australian centrepiece of an international program, whose ultimate aim is environmentally sustainable power generation by the controlled fusion of hydrogen isotopes. This facility is built around the existing H-1 Heliac experimental confinement device at the Australian National University, established under the Commonwealth Major National Research Facilities program, and recently upgraded as part of the Super Science Initiative. The research aims to build upon Australia’s internationally recognised position of excellence in basic plasma physics and applications such as plasma diagnostics and plasma processing, and to enable Australian scientists, engineers and industry to tackle the “grand challenge” problems presented by fusion research; this provides excellent postgraduate training and generates spin-offs with commercial potential.

The Facility is integral to the strategy for Australian fusion science and engineering, developed by the Australian ITER Forum, an association of over 160 scientists, engineers, students and others interested in the development of plasma fusion energy. The upgrades to heating, vacuum and diagnostics enable the facility to support the key elements of this strategy such as building Australia’s capability, and developing advanced instrumentation for fusion reactor prototypes, and ultimately ITER.

A new line of research into the interaction of fusion reactor materials with plasma was enabled by this upgrade, building on Australian expertise in extreme materials in Universities and ANSTO. The MAGPIE prototype linear plasma device (above) uses Facility heating, magnet and diagnostic infrastructure to produce plasma approaching conditions at the edge of fusion reactors, and analyse interaction of plasma with candidate wall materials. Research fields include Physics and technology of magnetically confined plasma, including its generation, heating, confinement, stability, interactions with materials, remote measurement systems and numerical modelling.

**Research Outcomes**

- A detailed understanding of the behaviour of hot plasma which is magnetically confined in the helical axis stellarator configuration, under the recently renewed IEA Implementing Agreement on Research into the Stellarator Concept.
- The development of advanced measurement systems (“diagnostics”), integrating optical and microwave detectors, real-time processing and multi-dimensional visualisation of data on large scale computer networks, and theoretical modelling.
- Fundamental studies of confinement, turbulence and transport of particles and energy in confined plasmas.
- Significant contributions to the global fusion research effort and an increased Australian presence in the field of plasma fusion power.
- Furthering knowledge of basic plasma physics and technologies for applications such as plasma processing of semiconductors, and plasma-material interaction, especially fusion reactor relevant materials.
- Improvements in skills of Australian industry in the areas of materials, modern power engineering, and communications and control.
Description
H-1 is a type of stellarator in which the plasma twists helically three times before closing back on itself to form a torus. By adjusting the relative currents in the coils (shown below), the H-1 configuration can be made to vary its shape and confinement properties; hence it is called a flexible heliac. The plasma in H-1 is heated by 50-400 kW of rf power at 4-20 MHz and a 200 kW, 28 GHz gyrotron microwave source. A large number (>100) of ports provide access for diagnostics, and many gate valves of various sizes allow convenient connection of user’s instruments. The MAGPIE linear device is readily accessible, and employs helicon wave heating in a converging magnetic field to create high plasma and power densities. A number of internationally unique diagnostic systems are being developed for application to both devices. These include:

- 21 channel millimetre-wave tomographic interferometry for electron density imaging;
- electrical probes to measure particle energies and fluxes, and several magnetic probe arrays for investigation of MHD/Alfvén instabilities;
- Coherence imaging spectroscopic systems for two dimensional measurements plasma temperatures, flows, and fluctuations;
- Supersonic helium beams for local spectroscopic measurement of electron temperature and density.

Applications
The Facility upgrades build on a major investment by the ANU, allowing Australia to capitalise on the current resurgence of interest in magnetic fusion configurations of the stellarator type. The flexibility of H-1 provides access to a wide range of configurations, including some with the promising “reversed shear” characteristic of advanced tokamaks, but without the drawback of multi-megampere plasma currents and associated instabilities. This allows H-1 and the MAGPIE facility to be used for basic studies or as a test-bed for divertor and edge diagnostics for ultimate application to the international fusion experiment, ITER.

H-1 and MAGPIE are Australia’s main experimental contacts with the international fusion community and H-1 is the largest plasma facility in the Southern Hemisphere. The Facility offers many diplomatically important opportunities for academic and technological exchange. Significant collaborative activities with Japan, Korea, China and Europe and the US are already under way, with exchanges of personnel and scientific equipment.

Availability
The Facility is available to all Australian physicists and engineers and is affiliated with AINSE. Scientists outside of the ANU are involved in all aspects of experimental program of the Facility. The data acquisition and analysis is readily conducted over the AARNET computer network, enabling data mining, remote access via metadata portals and grid computing. Proposals may be made at any time by contacting the Director, and scheduling of experimental time will be arranged between the applicant and the Facility Management Committee. Typical projects include development of new diagnostics, or use of the many existing diagnostics for studying wave, turbulence or confinement physics, or materials interaction, possibly leading to further experimentation on international devices.

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The Australian Positron Beamline Facility (APBF) provides a unique national facility for scientists to use positrons as an analytical tool for material structure, to study fundamental interactions of positrons with matter and bioscience activities. It was initially supported by the ARC through LIEF and Centre of Excellence grants. Participants included the ANU, Flinders, Griffith, Murdoch, Curtin, Adelaide, UWA, James Cook and Charles Darwin Universities and ANSTO. The APBF provides the only variable energy, positron beam lines in Australia. Positrons are emitted from a 22-Na radioactive source and are then accumulated and cooled, using gas-collision techniques, to form a positron cloud at room temperature (~30 meV). By modulating the well depth of the trap, pulses of positrons from nanoseconds to microseconds wide are produced, with a 100-1000 Hz repetition rate, and these are then used in two experimental beamlines.

The two positron beamlines are available for both high and low energy studies:

(i) The high energy (0.1-20 keV) beamline is dedicated to materials science studies. The pulsed beam is bunched to form a sub-nanosecond, positron pulse that can be injected into the surface of the material under study, with variable energy allowing control over the implantation depth. The positrons quickly thermalise after which they are attracted to open volume-type defects within the material. Fast detection techniques allow the decay time of the positrons within the material to be observed. The lifetime of the positrons in the vacancies and voids depends on the size of the free space in the material, and it is an excellent probe of defects in materials on the nanometre and sub-nanometre scale, and at depths up to several microns. The APBF is a unique Australian facility, and can be used to study a wide range of materials, from metals, to semiconductors to polymers. The variable energy makes it suitable for looking at thin films as well as bulk materials.

(ii) The low energy (0.1-200 eV), high-energy-resolution (~30 meV) beamline is used to investigate positron interactions with atoms and molecules, including measurements of ionization, annihilation and positronium formation. Important bio-molecules, and the fundamental interactions with them that underpin medical imaging processes such as Positron Emission Tomography (PET), are a main focus of study.

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A Dynaray 4 linear accelerator converted to deliver electrons in single pulses of up to 180 mA current. Pulse lengths available are 200 ns, 750 ns, 1.5 µs and 3 µs. Beam energy can be varied between 0.5 and 5 MeV but normal operation is at 4 MeV. Radiation dose per pulse can be set between 1-100 Gy. A range of optical cell path lengths between 0.5 cm and 3.0 cm as well as combined optical and AC conductivity detection cells of 1.0 cm and 2.0 cm are available for pulse radiolysis studies. Transient spectrophotometric detection is over 100 nm – 1000 nm using photomultipliers and photodiode detectors. Conductivity measurements are made using a 250 kHz AC system capable of handling up to 0.01 Ω-1. Optical and conductivity detection cells, combined with temperature control (4-90 oC), are also available, as well as a pre-pulse rapid-mix facility (under development). Both xenon (for uv-vis detection) and tungsten lamps (vis-red detection, and for long observation times, up to seconds) are available.

The modern, PC-driven, optical and conductivity radical detection system is operated in a LabView environment. Data is harvested/displayed by a 300 MHz digitizer/scope and full kinetic, spectral and conductance analysis is carried out using dedicated modern software. Data analysis can also be carried out off-line using stand-alone software as well as data sent to home institutions via the internet. Gas mixing lines (N₂, N₂O, O₂, AIR) are installed for saturating samples prior to pulse radiolysis and samples changed remotely between electron pulses.

The purpose built facility is located in the School of Chemical Sciences, at the University of Auckland. The full range of research facilities on site includes a ¹³⁷Cs gamma source providing a dose rate of up to 2.5 Gy min⁻¹ for complementary steady-state radiolysis studies. A fully equipped laboratory is available for sample preparation and analysis. Experienced radiation chemists are on the staff and can assist with experimental design and supervision of student research projects.

Pulse radiolysis experiments are used to identify radical intermediates and to study reaction mechanisms in solution by measuring time-resolved spectra and conductance changes. Electron transfer reactions between donors and acceptors are studied in real time. Conductivity measurements can be used to identify and study charged species that do not have accessible absorption spectra and to confirm the protonation state of species. Studies on complex organic and inorganic molecules as well as biological systems can be carried out. Temperature-dependent kinetic studies are used to obtain thermodynamic parameters for the studied reactions. Thermodynamic redox potentials of compounds and their radical intermediates are determined from radical equilibrium measurements with reference compounds.

Cumulative electron pulses for material science and sterilization studies are also available.

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