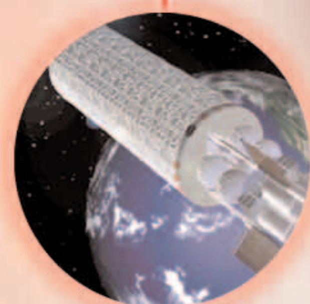
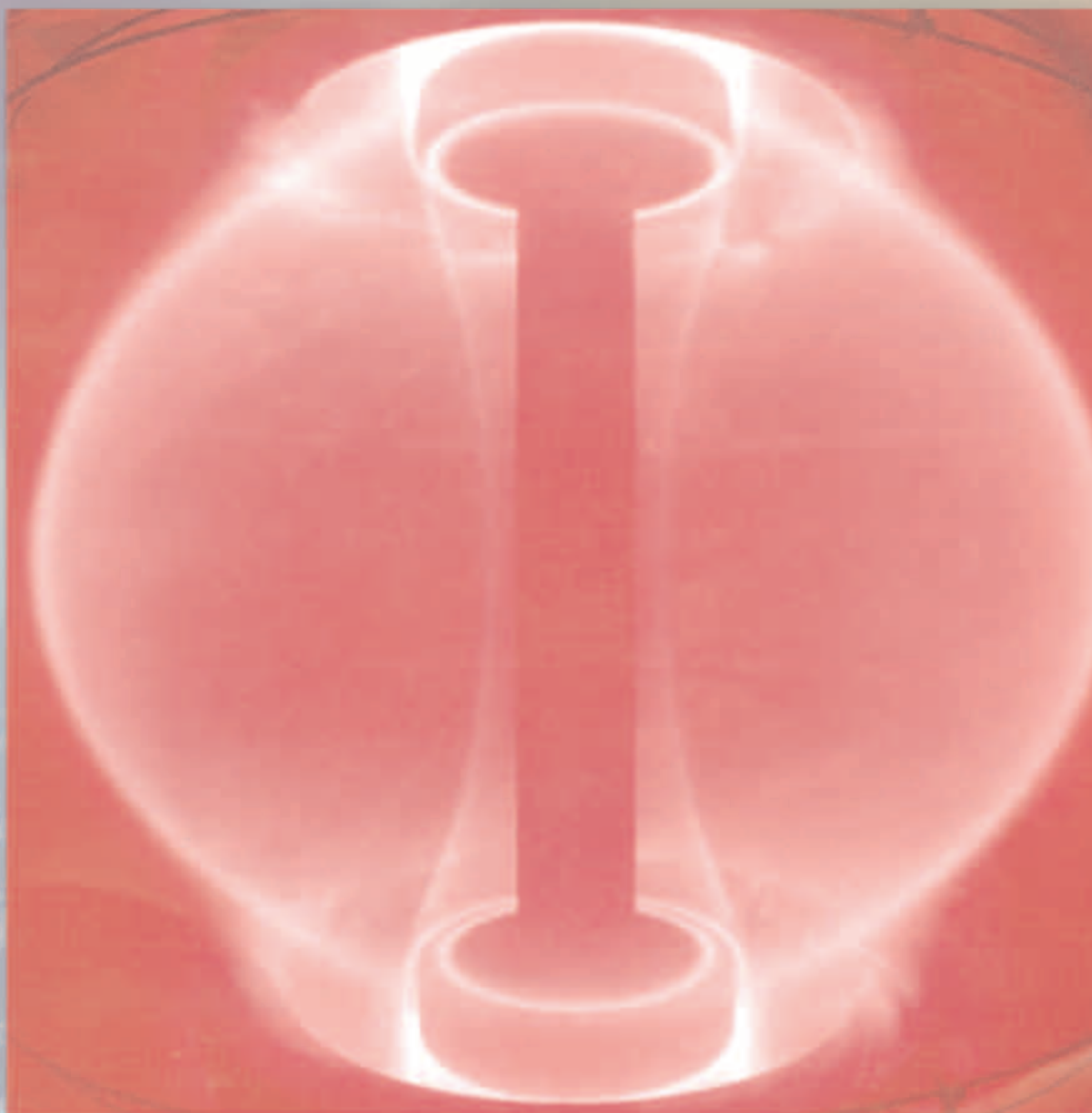
The Surprising Benefits of Creating A Star





Plasma discharge in the MAST Spherical Tokamak,
[courtesy of The United Kingdom Atomic Energy Authority]

The Surprising Benefits of Creating a Star

Since the 1950s, scientists and engineers in the U.S. and around the world have worked hard to make an elusive dream come true on earth: creating the reaction that fuels the stars (fusion). Practical fusion would be a source of energy that is unlimited, safe, environmentally benign, available to all nations and not dependent on climate or the whims of the weather. Initial optimism about the ease of creating a fusion reaction on earth soon gave way to the realization that this was an unparalleled technological and scientific challenge. While creating practical fusion energy has taken much longer than the early fusion pioneers anticipated, the work in overcoming the difficult challenges and the continued progress to date have brought with them unanticipated benefits in a wide variety of fields. This brochure provides insight into the nature of fusion research and describes some of the surprising benefits that have occurred in meeting this most difficult of challenges.

The Three Ways to Fuse Atoms

Fusion is the joining together of two atoms. Just as the positive poles of two everyday magnets push each other away, the positively charged nuclei of atoms also repel each other. In fact, the repulsive force between atoms is so strong that only extraordinary force will cause them to fuse. There are three primary ways to bring enough force to bear on atoms to make them fuse:

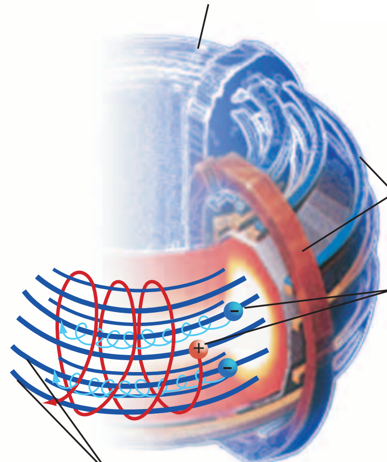
Gravity Confinement

The Eagle Nebula – A birthplace of stars

Gravity is the force that "gives birth" to stars by coalescing, heating and eventually fusing and igniting interstellar matter — this process takes millions of years. Gravity is also the force that holds stars together once they've formed. However, on earth we don't have sufficient gravity to confine a fusion reaction — not even close. So, researchers are looking at two very different ways of creating fusion here on Earth: Magnetic Confinement and Inertial Confinement.

Magnetic Confinement

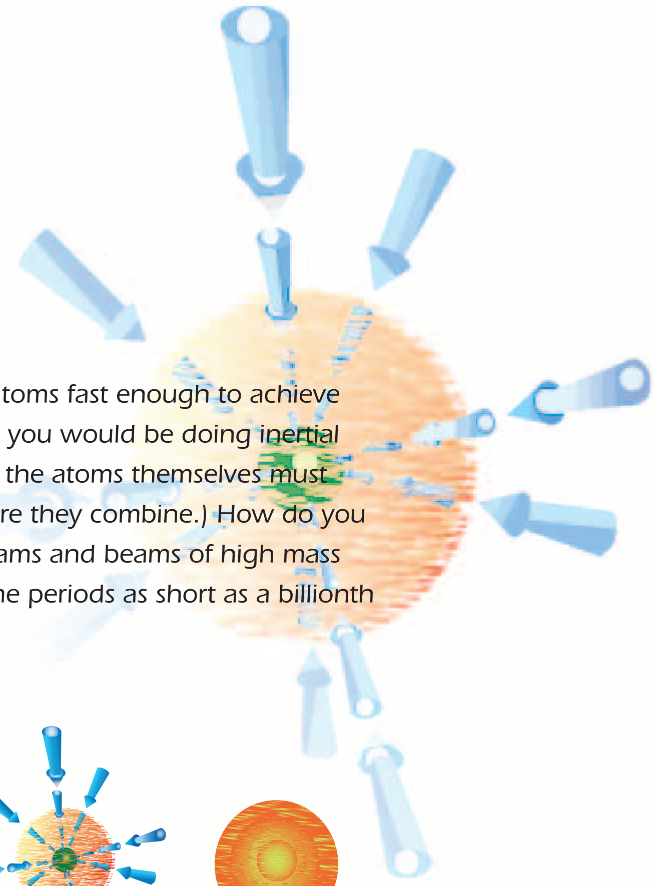
Since plasmas have an electric charge, they can be bent, compressed, confined and/or otherwise held by magnetic fields. So, a great deal of fusion energy research has been directed at using magnetic fields to control, confine and boost fusion reactions. Fusion occurs when a magnetically confined plasma is heated to a minimum of 100 million °C, kept under sufficient pressure, and held together.



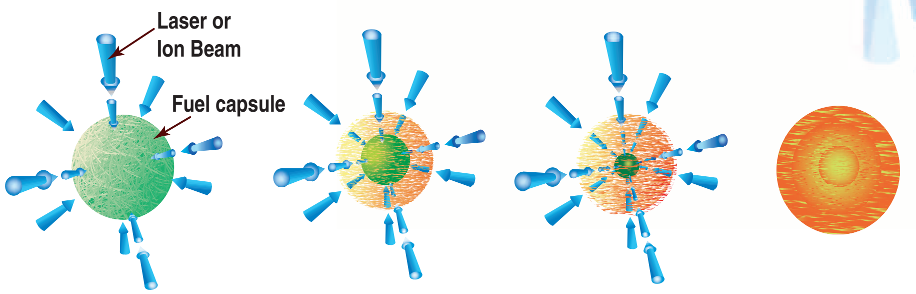
WHAT IS PLASMA?

Plasmas are one of four states of matter. The other three states are solids, liquids and gases. Each atom in a solid, liquid or gas is electrically neutral and is comprised of a positively charged nucleus surrounded by negatively charged electrons. However, when atoms are heated to many thousands of degrees, the electrons break away from the nuclei resulting in a gaseous "soup" of positively and negatively charged particles. This electrically charged gas is called a plasma. Understanding and controlling the extraordinarily complex behaviors of plasmas is one of the major scientific challenges facing fusion scientists.

Inertial Confinement



What if you could compress and heat a ball of atoms fast enough to achieve fusion reactions before the ball flies apart? Then you would be doing inertial fusion. (The term "inertial" refers to the fact that the atoms themselves must have enough inertia to resist moving apart before they combine.) How do you apply that force? Researchers are using laser beams and beams of high mass ions (from particle accelerators) to do this, in time periods as short as a billionth of a second.



Four steps of the inertial fusion process

WHAT IS A FUSION REACTION?

A fusion reaction takes place when two small atoms combine to form a larger atom. When this happens, substantial energy is released. This fundamental process of making bigger atoms out of smaller ones fuels the sun and the stars.

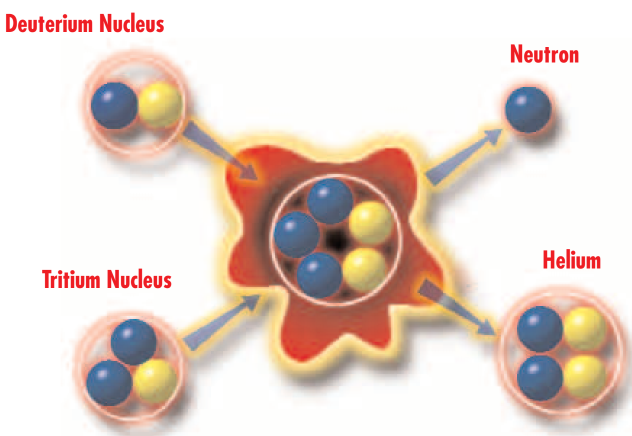
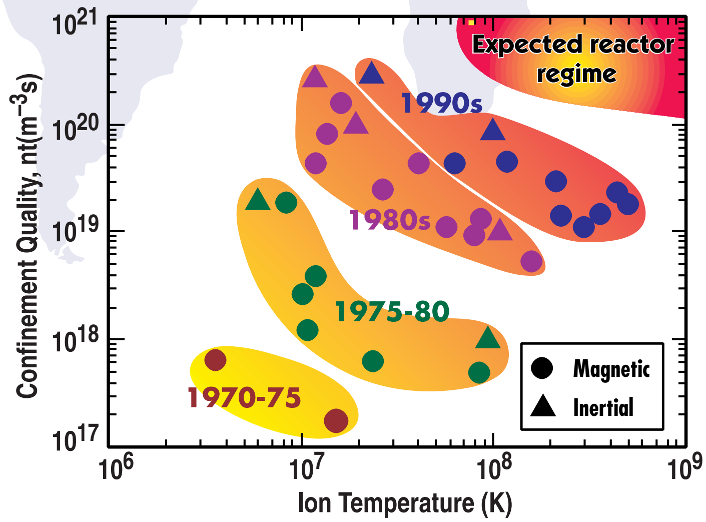


Illustration of the fusion process

Great Progress Equals Great Spinoffs and Contributions

Has There Been Any Progress in Fusion Research?

The answer to this question is a resounding "Yes!" There is no longer debate about whether controlled fusion can be done in the laboratory — it has already been achieved. This was definitely not the case in the 1980s or early 1990s. Although controlled fusion in the laboratory today is still a long way from tomorrow's practical and reliable power plant, the scientific understanding of plasma's complex behavior has been revolutionized in this past decade. A measure of this can be seen in the plasma Confinement Quality [the product of the plasma density (n) and the plasma retention time (τ) as a function of the plasma temperature (°K)], which shows a steady progress, over the last three decades, towards the conditions expected in a reactor.



One measure of progress in fusion research from 1970 to 2000

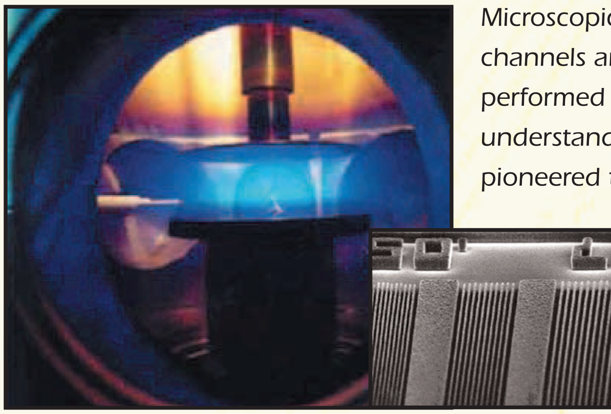
THE TOUGHER THE CHALLENGE MET, THE GREATER THE BENEFIT

Many have called the creation of practical fusion energy the most difficult scientific and technological challenge ever undertaken. Although fusion has now evolved from a dream to a laboratory reality, there are still major challenges that must be met before it can become a practical energy source. Addressing these challenges has and will continue to yield rich benefits for other fields of science and technology. Areas of understanding and technology that continue to be improved include:

- The complex physics of plasmas
- Cutting edge computational capabilities
- Sophisticated methods for heating fusion plasmas to hundreds of millions of degrees
- Innovations in materials, magnets and control mechanisms (primarily magnetic fusion)
- Creation of new diagnostics and sensors. (How do you measure temperatures, pressures, and other parameters in something that's 100,000,000 °C?)
- Complex engineering innovations (heat removal, remote maintenance, impurity removal, etc.)
- Micromachining and manufacturing (primarily inertial fusion)
- Extremely accurate tracking and targeting (primarily inertial fusion)

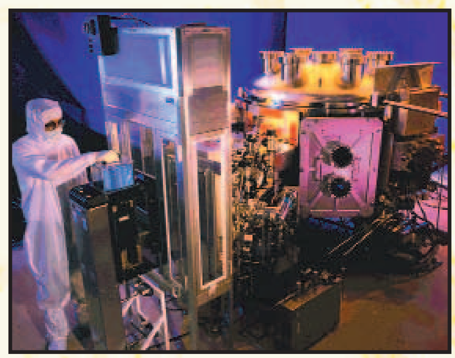
Fusion Research Yields Better Semiconductors

Semiconductor manufacturing is the area in which fusion research and technology has made the greatest commercial impact. Large wafers and small-scale components would not be practical without the tools and technologies adapted from fusion.



Microscopic etching and deposition of conducting channels and components on silicon wafers is now performed in plasmas controlled through the physics understanding and plasma dynamics pioneered through fusion research.

Parallel plate plasma etch system



Ion beam sputter deposition system

Improved optics developed through laser fusion research play a key role in producing and aligning the templates that control the deposition and etching of the microscopic channels and components on semiconductor wafers.

Helios synchrotron (Oxford Instruments)

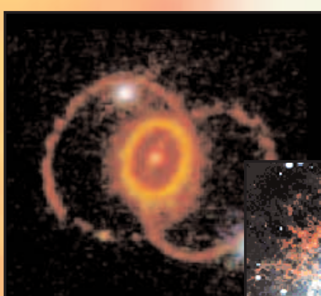
The development of intense ultraviolet and/or x-ray devices through fusion research is likely to make even smaller and faster semiconductor devices possible in the near future.

Better Understanding the Physical Universe

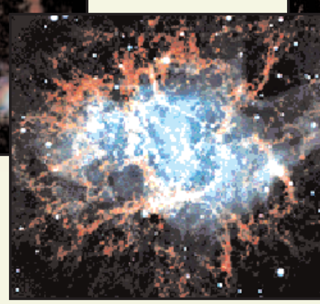
In overcoming the challenges of fusion production and control, the boundaries and understanding of science in related fields is being advanced.

Simulating Supernova (and Other Fantastic Phenomena) on Earth

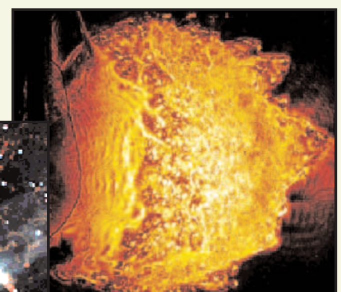
Astrophysicist and space physicist are faced with the problem of deciphering the few clues that observations provide in order to learn about the nature of stellar objects. (The clues most often consist of plasma radiation, and a full familiarity with what plasmas actually radiate is needed in order to learn about the astronomical objects.) Astrophysical phenomena can be investigated with experiments on intense lasers or by computer simulation. Some of the areas that are being studied are: the hydrodynamics of supernova remnants, relativistic plasmas and gamma-ray bursts, behavior of dense hydrogen in Jupiter, magnetohydrodynamics in the Crab Nebula, turbulent hydrodynamics in supernovae, and radiatively cooled hydrodynamic jets.



Supernova remnants



Magnetohydrodynamics of the Crab Nebula



Hydrodynamics in Supernovae

Understanding the Core of Jupiter

Nova laser shock compression test chamber

High-power pulsed lasers built for fusion research are being used to explore the high-energy relationship between the volume, temperature, and density for some elements. The shock compression conditions achieved by pulsed laser implosions can duplicate the conditions found at the core of large planets such as Jupiter.

Behavior of dense hydrogen in Jupiter

Better Eyes on the X–ray Universe

Multi-mirror mission x-ray telescope

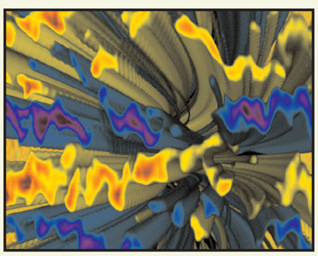
Fusion scientists have helped build an x-ray spectrometer grating for the Multi-Mirror Mission (XMM). The new spacecraft will provide a more than 10-fold improvement in sensitivity and resolution, and will send back a wealth of new information about the x-ray universe, akin to that provided by NASA's Hubble Telescope about visible light radiation.

Dr. Nancy S. Brickhouse
Research Astrophysicist
Chandra X-ray Observatory Center
Harvard-Smithsonian Center for Astrophysics
Cambridge, Massachusetts

"My role at the Chandra X-ray Observatory is to provide the astronomical community with tools to analyze x-ray spectra. Chandra is now taking x-ray grating spectra of all kinds of exotic space objects, which must be interpreted through plasma spectra models. The same types of models I used for fusion plasmas are still in demand."

Dr. Brickhouse was a fusion researcher at the University of Wisconsin concentrating on impurity production mechanisms in fusion plasmas. She has a Ph.D. in Physics from the University of Wisconsin at Madison and a B.S. in Physics from the University of North Carolina at Chapel Hill.

Nonlinear Dynamics



Volume rendered visualization technique

When extreme amounts of force or energy are applied to something, its behavior can become unpredictable and chaotic, as observed in a chemical explosion. The study of this type of behavior is called nonlinear dynamics and has been a cornerstone of the theoretical work performed on fusion plasmas. Since the underlying properties of fusion plasmas follow fluid dynamics, the same nonlinear dynamic models and theories developed in the fusion program are being applied to other science areas such as: instabilities at fluid interfaces (a difficult and centrally important issue for fluid dynamics, and impacts such questions as the rate of heat transfer by the Gulf Stream, resistance of pipes to fluid flow, combustion rates in automotive engines, and the late time evolution of a supernova); dynamics of fluidized beds, spatial patterns and shock waves in granular flows; and crack propagation in crystalline and amorphous materials.

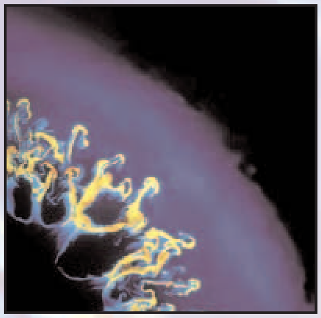
Dr. Sid Karin
Director, San Diego Supercomputer Center
Director, National Partnership for Advanced Computational Infrastructure
Professor, Computer Science and Engineering
University of California, San Diego

"The fusion community was the first unclassified scientific community to use supercomputers, and as a fusion researcher, that's where I received my first exposure to supercomputers. Fusion scientists were the pioneers in supercomputing for the rest of the scientific community."

Dr. Karin, formerly a fusion researcher at General Atomics, conceived of and founded the San Diego Supercomputer Center in 1985. He received his Ph.D. in Nuclear Engineering from the University of Michigan, a M.S.E. in Nuclear Engineering from University of Michigan and a B.E. in Mechanical Engineering from City College of New York.

Better Understanding the Physical Universe *(continued)*

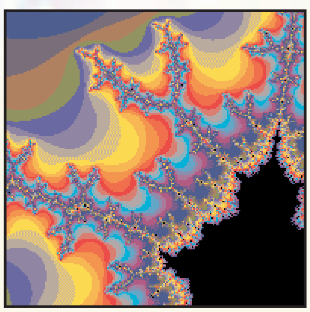
Turbulence and Transport



Turbulent transport in Supernova 1987A

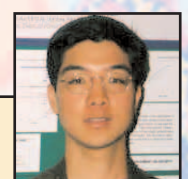
The presence of enhanced transport of particles and energy across the confining magnetic field represents a main obstacle in achieving fusion by magnetic confinement. Experimental data suggests that this so-called anomalous turbulent transport is caused by fluctuations in the plasma. The massively parallel computers now becoming available can relax the limits that have constrained computational research for decades in the arena of turbulence and transport. Earlier computer models could represent small- or large-scale disturbances separately, but could not simultaneously resolve multiple scales, a key feature of strong turbulence. With massively parallel processing (MPP), scientists can now study these important physics issues. The ability to model the transport of neutral particles (such as neutrons and photons) through matter is important to many scientific and engineering activities. Among these are reactor and shielding design, development of medical radiation treatment, and nuclear well logging applications.

Chaos Theory



Fractal image

Chaos theory is a branch of nonlinear science dealing with relatively complex open systems and systems that are displaced from stable equilibrium by means of a flow of energy, matter, or information. Chaos Theory, with its notions of bifurcation points, fractals, self-organization and solitons, has become a powerful metaphor over the last two decades. The theory has been applied to everything from physics and biology to weather, the stock market, earthquakes, population size, spread of disease, linguistics, elementary particles, psychological states, etc., and has even crept into films and novels.



Dr. Ernest Lo
Research Assistant, Department of Biology
McGill University and University of Quebec, Montreal, Canada

"My research involves computer modeling of tree growth and form. The model simulates the growth of an individual tree from a seed, taking into account light conditions and self-shading in the tree, and the placement of buds, branches, leaves and wood in a three-dimensional tree architecture. The model is intended for practical applications such as the forecasting of tree growth and survival in forests.

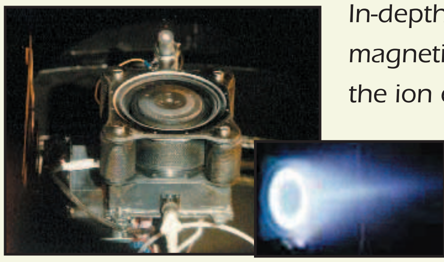
"My experience in fusion has benefited this work in many ways. The level and complexity of scientific relationships in physics is unparalleled and gives one insights and skills to look for similar patterns or structures in the theories and ideas of other fields, such as ecology and botany."

Dr. Lo has a Ph.D. in Plasma Physics from Princeton University and a B.A.Sc. in Engineering Science from the University of Toronto.

Improving Our Reach into Outer Space

By applying plasma technologies learned in fusion research, advanced space thrusters are being developed and improved. These new propulsion systems, by yielding substantially more thrust per pound of fuel and much higher velocities, will make space flight more affordable and make interplanetary missions more practical.

Plasmas, Magnetic Fields and Today's Satellites



Hall thruster D-100 TAL

In-depth knowledge of plasmas interacting with magnetic fields is allowing fusion scientists to improve the ion engines now used on many satellites.

Going to Mars With A Plasma Rocket

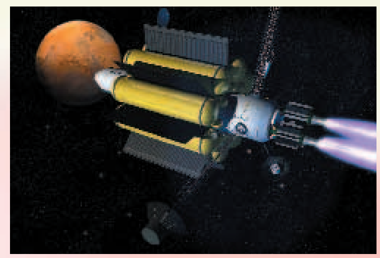
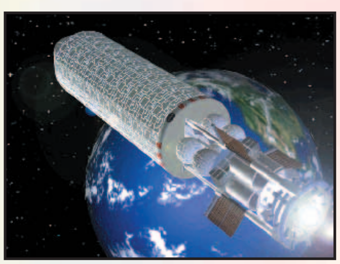


Illustration of the VASIMR Mars rocket

NASA, in collaboration with experts from fusion laboratories, is developing a new type of rocket technology, the Variable Specific Impulse Magnetoplasma Rocket (VASIMR). The VASIMR drive is not powered by conventional chemical reactions as today's rockets are, but by radio frequency energy that heats the propellant. The propellant is a plasma that reaches extreme temperatures and very high velocities as it is expelled from the rocket. This new type of technology could dramatically shorten human transit times between planets.

Fusion Reactors and Space Flight



Magnetized target fusion propulsion

Fusion propulsion promises thrust levels 1,000 times higher than conventional rockets, enabling routine human missions anywhere in the solar system at almost any time. Of the thirty or so fusion concepts that have been identified by DOE, at least half a dozen can be used for propulsion. NASA scientists and engineers plan to use the expertise and facilities of the DOE labs and their affiliated universities to identify and explore technologies that can lead to practical space travel.

Dr. Chang-Diaz
NASA Astronaut
Director, Advanced Space Propulsion Laboratory
Lyndon B. Johnson Space Center, Houston, Texas
Adjunct Professor of Physics: Rice University, University of Houston, and University of Alabama

After obtaining his Ph.D. in the field of applied plasma physics and fusion technology from the Massachusetts Institute of Technology (MIT), Dr. Chang-Diaz joined the technical staff of the Charles Draper Laboratory. His work at Draper was geared strongly toward the design and integration of control systems for fusion reactor concepts and experimental devices, in both inertial and magnetic confinement fusion. In 1979, he developed a novel concept to guide and target fuel pellets in an inertial fusion reactor chamber. In 1980, he conceived the VASIMR engine, a new type of rocket based on high temperature plasmas. He presently leads a research team from NASA, academia, private industry and the Department of Energy in the development of this system for human and robotic space applications.

"In the last 30 years progress in fusion technology has been relentless and steady, leading to remarkable advances in plasma physics and associated technologies. The development of VASIMR builds on these advances, providing an evolutionary path for further technology growth, but with exciting and immediate applications en-route."

Dr. Chang-Diaz earned his B.S. in mechanical engineering from the University of Connecticut.

Fusion Research and Innovations

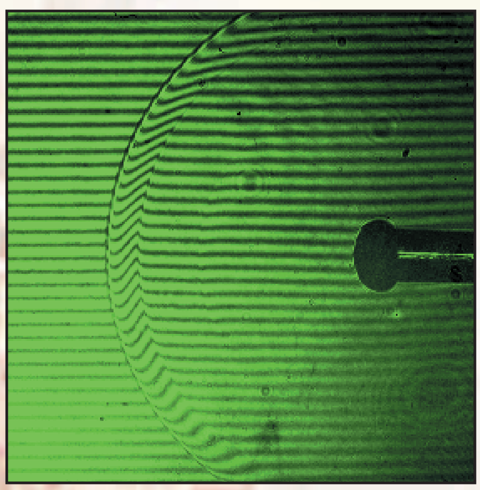
Fusion scientists working with experts in the medical and health fields have helped doctors visualize objects within the human body without invasive surgery, perform corrective surgery with less trauma and quicker recovery, reduce the quantity of food lost to spoilage and contamination, and create a new way of excavating cavities in teeth without drilling.

Viewing Tumors without Surgery

Open air MRI machine

Large bore superconducting magnets, a technology driven by fusion research have led to the development of Magnetic Resonance Imaging (MRI), which has given the medical profession an important new tool for locating and identifying tumors and abnormalities without risky exploratory surgery.

Re-establishing Blood Flow to the Brain

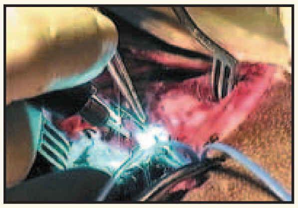


Stress wave created by laser pulse through optical fiber

Fusion researchers have developed unique technologies to aid in the disruption of thrombus occlusions (blood clots). This minimally invasive technique, Endovascular Photo-Acoustic Recanalization (EPAR), involves guiding a catheter to the site of the occlusion and introducing an optical fiber delivery system into the catheter. Laser light is coupled into the optical fiber and delivered to the occlusion, causing mechanical disruption of the occlusion and re-establishing blood flow to the brain.

in Medicine and Health

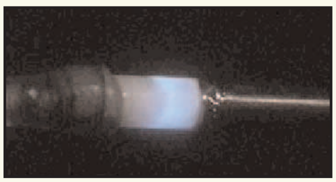
Improved Surgical Incisions



Laser welding of an artery

The Ultra-Short Pulse Laser developed in the fusion program can be used as a surgical tool to create high-precision cuts without damaging surrounding tissue, or for tissue welding. Lasers are used because they have the ability to accurately control the volume of tissue that is exposed to the activating energy.

Keeping Arteries Open with Radiation



Laser drawn x-ray catheter

An x-ray catheter system to address a key element of heart disease treatment has been developed out of inertial confinement fusion. Following balloon angioplasty to reopen occluded cardiac arteries, scar tissue often forms in the artery during the natural healing process, blocking blood flow. Known as restenosis, this clogging requires repeated surgery. Research has shown that treatment of the arterial wall with ionizing radiation immediately after angioplasty can prevent restenosis. The x-ray catheter is a safe, cost-effective means of delivering this ionizing radiation in the form of x-rays.

Dr. Niels Otani
Associate Professor
Department of Biomedical Engineering
Case Western Reserve University, Cleveland, Ohio

From Fusion Research to Heart Rhythms

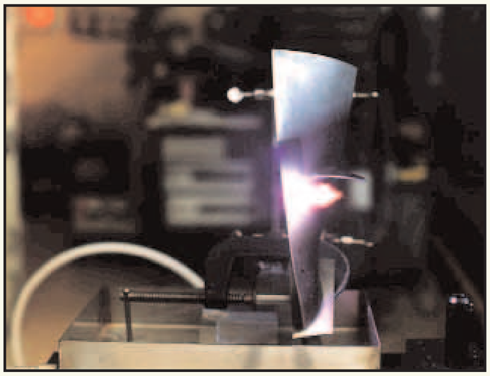
"Some 400,000 people in the U.S. die each year from heart rhythm disorders, often as the result of coronary disease or heart failure. In fusion research, I used a combination of electrodynamics, statistical thermodynamics, nonlinear dynamics, and computer simulation techniques to study the behavior of plasmas. Now, in my current research, I apply these same tools to improve our understanding of abnormal cardiac rhythms. I hope to be able to explain when and how these bad rhythms occur, and discover new therapies for stopping or preventing them."

Dr. Otani was a fusion researcher at the Lawrence Livermore National Laboratory in the 1980s specializing in the behavior of plasmas. He received his Ph.D. in Physics from the University of California, Berkeley in 1986, B.A. Honors in Physics from the University of Chicago, with degree requirements also satisfied for a B.S. in Mathematics.

Making Better Materials

The material science world is increasingly challenged to produce materials with greater endurance, and harder surfaces; materials that have less friction, less wear and that provide more resistance to corrosion. This effort is strongly supported by fusion research and technologies.

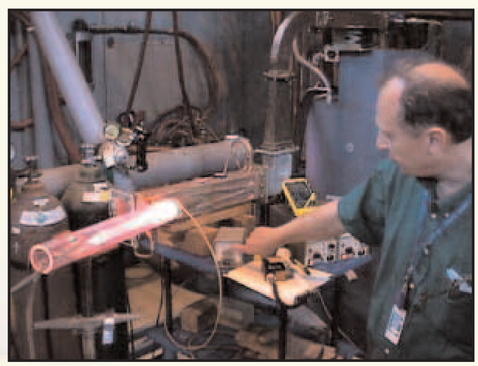
New Lasers and Improved Cutting Techniques



Laser shot peening

Petawatt lasers, developed for the inertial fusion program, have been used for high-precision laser cutting and machining. The ultra-short pulses are too brief to transfer heat or shock to the material, so cutting, drilling, and machining can occur without damaging surrounding material. The laser can also help produce high-quality thin films by ablating (blowing off) material. The high-energy plasma generated during ablation allows the deposition of smooth films containing no particulates.

Improved Microwave Sources Yield Better Ways to Process Material



Carbon fiber processing by direct microwave heating

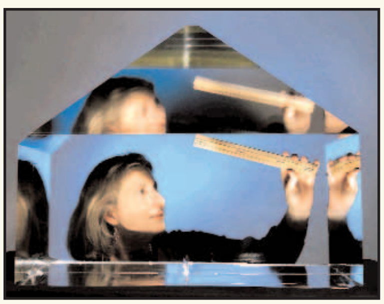
Ultra-high frequency microwave sources developed for the magnetic fusion program are being applied to a wide variety of material processing activities. Direct volumetric heating drastically speeds processing times and increases process efficiency. Some processes, such as ceramic sintering, occur more rapidly and at lower temperatures than with conventional heating methods, improving the final product. Microwave processing has numerous potential applications, including wood processing (drying, cracking, treating); grain or agricultural processing (drying or insect decontamination); chemical processing (dry or liquid); flash pyrolysis (vaporization using very fast heating rates) and others.

Hardening Materials with Ion Implantation

Varian Associates model CF3000 200 kV ion implanter

Ion source technology developed as a plasma heating tool has been used to modify the surface property of many materials. Energetic ions can be used to modify film density, stress, texture, grain size, interface structure, and other related properties. Over the past decade, ion implantation, the most visible ion beam processing (IBP) technology, has been able to find a technical and commercial niche improving the wear properties of medical devices such as titanium hip and knee joints. Ion implantation has also been widely used in the semiconductor industry for more than thirty years to provide precise control of semiconductor wafer manufacturing. Other applications include the aerospace, automotive, and cutting tool industries.

Growing Crystals



Potassium hydrogen phosphate (KDP) crystal created by rapid growth method

The pursuit of better and cheaper crystals for laser fusion has yielded a "rapid-growth" method to produce the world's largest single crystal optical elements. By understanding and then controlling the crystallization process at the molecular level, complex microstructures can be synthesized that will affect many disciplines and technologies, ranging from life-saving pharmaceuticals (such as crystallized proteins, among them human insulin) to new optical materials.

Reducing Friction with Diamond Film Coatings

View inside the process chamber showing 1000 aluminum automotive pistons having a diamond-like-carbon coating applied

High-voltage pulse power equipment used for fusion plasma heating research has been adapted to coat parts with a low friction diamond-like-carbon film. This process is very attractive to the automobile, aircraft, and machine tool manufacturers who have long sought ways to enhance the surfaces of light-weight alloy parts to improve wear lifetimes.

Improving The Environment

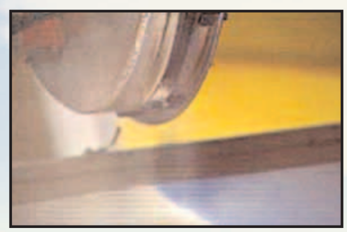
While fusion energy has great potential to improve the environment in the future, the path to fusion itself already has yielded important new environmental technologies. Increasingly, large volumes of toxic waste (created by manufacturing and by production and consumption of raw materials) requires innovative treatment. Plasma, microwave, and cryogenic technologies developed and associated with fusion research are in use today. In addition, plasma technologies are helping make more efficient use of natural resources.

Destroying Hazardous Waste

Electrodeless plasma torch (MIT)

Fusion research on microwave-heated plasmas has produced a plasma torch. This provides an environmentally superior treatment for waste remediation by providing processing free of hazardous emissions. This process could provide a rapid, efficient, reliable and simple technique to selectively melt, vitrify, or remediate contaminated soils, or objects at any depth underground. It appears to overcome most of the limitations of techniques using fossil fuels and electric heat sources.

Fusion Reactor Fueling Yields Decontamination Technique



CO_2 cryoblaster (ORNL)

The ultra-high speed injection of cryogenically frozen pellets of fuel into the burning plasma is a key technology being developed for fueling a fusion reactor. This has fostered a technique for cleaning contaminated surfaces using frozen carbon dioxide pellets shot at high speeds. The effect is similar to sand blasting. The high-speed frozen pellets are an effective cleaning agent and leave no residue (other than the removed contamination itself) when they warm up and evaporate. A major attraction of this technology is its potential to minimize the generation of hazardous, radioactive, and mixed wastes in the cleanup of nuclear facilities.

Reducing Air Pollution with Plasmas

Plasmatron (MIT)

Understanding basic plasma behavior has led to the development of the microplasmatron fuel converter (plasmatron), a device that would be used on a vehicle to transform gasoline or other hydrocarbons into hydrogen-rich gas. The plasmatron uses a plasma to accelerate reactions that generate hydrogen-rich gas. The hydrogen gas, a high quality fuel, will greatly reduce pollution from the vehicle.

Tackling Tough Scientific and Technical Problems Results in Spinoffs

Because of the sheer difficulty of creating fusion energy here on earth, numerous new scientific frontiers and technologies have been and are being created. Many of these innovations and insights are proving to be invaluable in applications far afield from fusion energy research.

Already the tools, diagnostics, modeling and basic understanding for the generation and control of intense fusion plasmas has lead to improvements and understanding in the areas of semiconductor chip fabrication, observation and understanding of the phenomena occurring in the universe around us, advanced space thrusters, medical testing and surgical procedures, enhanced surface properties of materials, and hazardous waste decontamination and destruction.

Besides these contributions to so many scientific and technological areas, another significant contribution is the cadre of scientists and engineers who have worked and trained in the pursuit of fusion energy and have taken their skills and knowledge out to the world scientific community.

WILL THERE BE MORE SPINOFFS?

History has shown that the more difficult a scientific and technological task is, the more new ideas and technologies have to be created to achieve it. Fusion will undoubtedly continue to be a particularly productive source of spinoffs in the years to come.

Spinoffs

TECHNOLOGY

Semiconductor Manufacturing
- Large area plasma etching and deposition
- Extreme Ultra Violet Lithography (EUVL)
- Thin film deposition EUV masks
- Precision EUV optical elements
- X-ray microlithography
- Direct write e-beam array using nanotube electron field emitters
- Ion implantation
- Plasma HDTV display panel

Space Propulsion
- Hall thrusters
- RF drive (VASIMR Project)

Waste Remediation
- Plasma torch
- Waste glassification
- Cryopellet ablation
- Isotope separation
- Microwave spallation of contaminated surfaces
- Plasma-assisted catalyst
- High Sensitivity Continuous Emission Monitor (CEM) for metals in stack gas

Material Processing
- Laser peening
- Ion beam surface modification
- Microwave sintering
- Enhanced Plasma Chemical Vapor
- Deposition (EPCVD)
- Optical material manufacturing
- Rapid crystal growth
- Laser machining

Pulsed Power & Power Conversion
- IGBT power conversion units for trains, buses, and earth movers
- Microwave Impulse Radar (MIR)
- Power generation, transmission, storage, conditioning, surge limiting, & motors

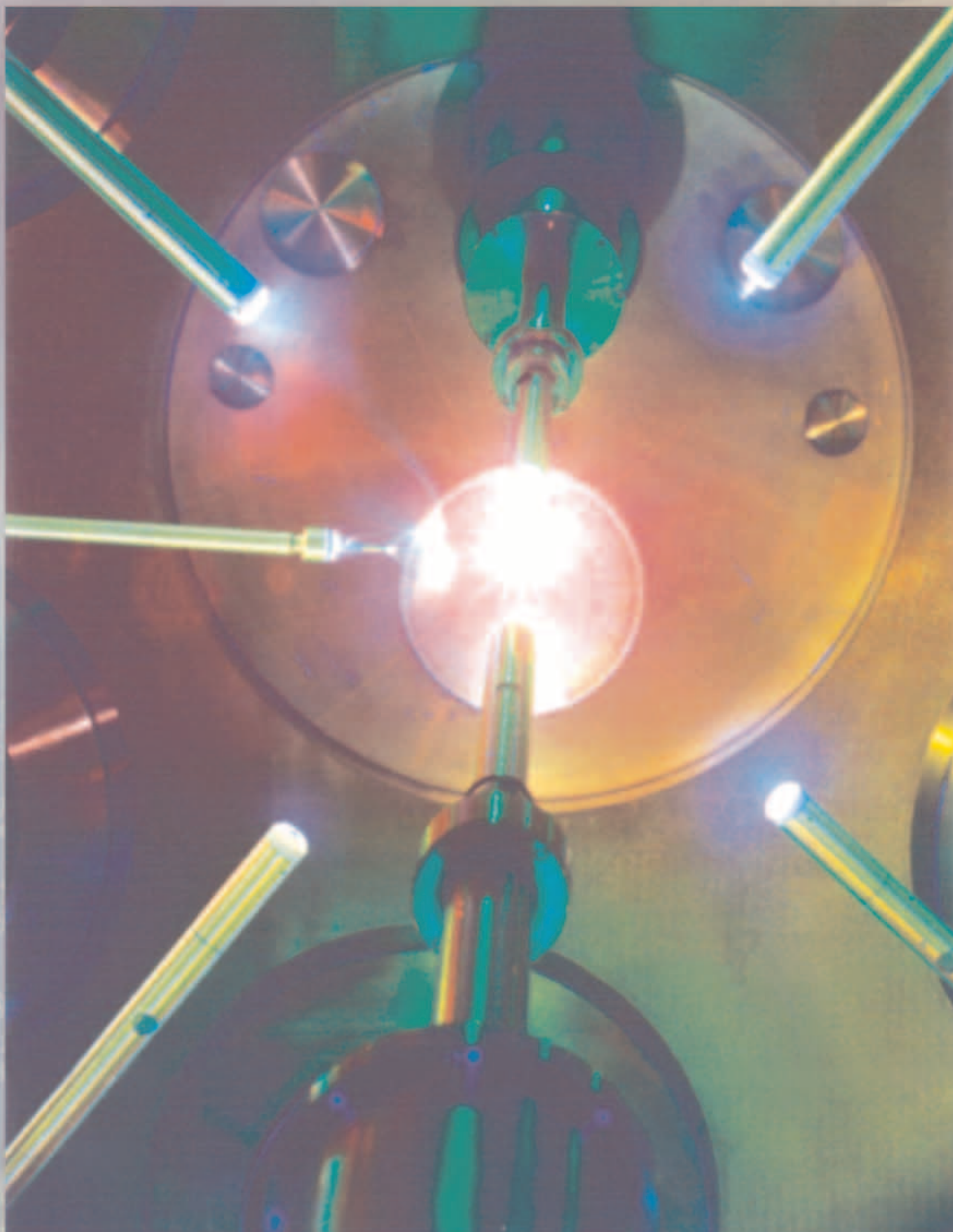
Superconductivity
- Nuclear Magnetic Resonance (NMR)
- Superconducting cyclotrons for isotope production and neutron radiography
- Superconducting synchrotrons for X-ray lithography
- Magnetic separation of materials (e.g., clay)
- Magnetic Resonance Imaging (MRI)

Medical/Health
- Laser cavity drilling
- Medical isotope separation (laser/rf)
- Tissue welding
- X-ray catheter
- Continuous glucose monitor
- Opto-acoustic laser system for blood clot emulsification
- Dental imaging
- Grain sterilization & milk pasteurization
- Magnetic Resonance Imaging (MRI)

SCIENCE
- Laboratory Astrophysics
- Simulation of Supernova Instabilities
- Simulation of radiatively cooled jets
- Dense matter (metallic hydrogen)
- Planetary science of giant planets and brown dwarf stars

Diagnostics
- X-ray spectrometer
- Laser anemometer
- High-dynamic-range high-speed streak cameras

Code Development
- Turbulence
- Astrophysics
- Nonlinear Dynamics
- Chaos Theory



Laser irradiation of a target in the OMEGA Target Chamber
[courtesy of the University of Rochester]

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