coil systems which must be meticulously designed and constructed to withstand tremendous forces. Together with the power supplies and control subsystems, the magnet systems required for fusion rival the largest and most sophisticated electrical equipment ever constructed.

To tackle this problem, MFE scientists and engineers have developed innovative approaches to magnet design that include computer-aided-design and other sophisticated design tools. For example, EFFI is a computerized tool created to design the complicated magnets found in tandem mirrors and other fusion devices. This computer program computes the fields, forces and inductance of magnetic coils of almost any shape. It eliminates the need to experiment or perform calculations based on scale models. It is in use not only on a National scale within the United States but is also used in Germany and Japan.

Fusion scientists have also improved magnet conductors and fabrication methods dramatically. Design tools in hand, they have found ways to use nonmagnetic materials for supporting structures, thereby leading to a major reduction of mechanical stresses within magnetic systems. One such material, Nitronic 33, is a relatively high strength nonmagnetic stainless steel alloy, which is used in the supports and cases of the TFTR's main coils. The forgings used in the TFTR are the largest ever fabricated from this material. Detailed knowledge of the mechanical and thermal environment inside a large magnet also provided the capability to establish the engineering parameters and performance goals for other innovations, such as methods to obtain high strength bonds between conductors and their insulation and new technologies for welding metals particularly adapted to use in the high-field-strength superconducting magnets.

The result of this progress is the capability to design and construct conventional and superconducting magnets of unprecedented size and power to confine the dense, high temperature plasmas into the shapes needed for fusion reactors. Magnet technology is keeping pace with program needs by building the magnets needed today and the information data base that will make it possible in the future to design, construct, and operate the magnet systems for a fusion reactor.

High Vacuum Technology – The development of techniques for large scale titanium getter pumping, the state-of-the-art in high vacuum technology for over 20 years, can be traced directly to the MFE Program.

The plasma fuel of a fusion reaction must be surrounded by a large vacuum chamber to prevent impurities from contaminating the plasma fuel and to aid in the removal of spent fuel and other fusion byproducts which could impede the fusion cycle. A full vacuum—a gaseous density 1/10,000 that of air—must be maintained continuously, despite cyclic releases of spent fuel and fusion byproducts consisting primarily of hydrogen isotopes and helium. When magnetic fusion research began, conventional vacuum technology could not satisfy this requirement.

To overcome this limitation, fusion researchers had to push vacuum system technology well beyond the then state-of-the-art. Significant advances were based on the chemical concept of gettering, a mechanism by which gaseous impurities are drawn into a vacuum pump by a special chemical (a "getter") which attracts specific gaseous molecules to its surface where they are chemically bonded and thus "sucked" out of the vacuum chamber. Chemical "gettering" of gases had long been used in vacuum tubes; and although it presented a conceptual solution to the problem, no one had attempted such a large scale application of

Magneform

Magneform is a versatile process that allows metals to be welded without heat, riveted without hammering, and shaped without being touched. Hundreds of products are made or assembled using this innovative application of pulsed intense magnetic fields. These vary from metal baseball bats and sanitary caps on bottles of vaccine to automobile fuel pumps and airplane wings. Some, such as disposable cigarette lighters, would not be possible without magneformed parts.

The roots of magneform are in early magnetic fusion devices designed to "pinch" or compress the plasma to fusion conditions. Some of these devices required thin metal liners, and the magnetic fields tended to crush the liners. The fusion experimenters recognized the phenomenon's potential, patented it, and quickly redirected it to performing difficult tasks around the laboratory such as attaching connectors to large electrical conductors. Soon after, the General Atomic Company obtained an exclusive license for use of the Federally owned patent for magneform and developed a small business in magneforming.

Today, high volume assembly lines in the automotive, aerospace, energy, aircraft, electrical, defense, and other major industries throughout the world use the magneform process for fast, simple, high-quality, and economical production. Production cost savings in excess of 60 percent compared with alternative processes are achieved. The manufacture of magneform equipment is a $4 million per year enterprise for Maxwell Laboratories, Inc. The users of magneform realize production cost savings in excess of $8 million annually.