Plasma Confinement (N-tau) – The fuel confinement time (seconds) and density (particles/cubic centimeter) of ionized nuclei in the plasma combine in a factor termed **N-tau**. A British scientist, J.D. Lawson, determined that for break-even to occur, N-tau has to be 100 trillion and the plasma temperature must be 70 million degrees Celsius. There is a permissible trade-off, however, between plasma density and confinement time—the greater the density, the less the confinement time and vice versa. The most difficult challenge of the past 30 years has been to reach an N-tau of 100 trillion. In 1983 United States fusion scientists reached it on the Alcator C machine and in 1985 duplicated their success on the TFTR.

Plasma Temperature – The temperatures needed for break-even as well as the higher temperatures needed for economic reactor operation have both been achieved. For break-even to occur, a plasma has to reach at least 70 million degrees Celsius; and for a power reactor, which will require an energy gain greater than 1.0, 100 million degrees Celsius is needed. Fusion research passed the first goal in 1979 when the PLT produced headlines around the world and a temperature of 75 million degrees Celsius. In 1985 the 100 million degree Celsius threshold was reached on the TFTR, and in 1986 that record high was extended beyond the 200 million degrees Celsius mark.

Magnetic Confinement Efficiency (Plasma Beta) – An indicator termed **beta** is used by the fusion community to provide another important estimate of progress towards a commercial fusion power plant. Beta addresses the relationship between the magnetic forces confining the plasma and the forces driving it to expand as it is heated up. Beta is, then, a measure of the efficiency (expressed as a percentage) with which the magnetic field confines the plasma fuel while fusion occurs.

All investigations into the form of a possible fusion power reactor focus on beta. Since one-fourth to one-third of the cost of a commercial reactor may be attributable to the magnet systems, beta values are directly related to the economics of fusion power production. For this reason, beta will play an important role in future assessments of the engineering and economic feasibility of fusion reactors. High plasma beta values imply high power levels for each dollar of investment and lead to better power plant economics.

Several tokamak experiments have produced data on beta. Values of 5 percent have been achieved, approaching the 7 to 10 percent value estimated as sufficient for an operating reactor.

Development of Theoretical Understanding

The outstanding recent improvements in optimizing plasma behavior have been made possible by rapid advances in plasma physics, and computational physics. Plasma confinement now rests on a solid theoretical understanding of the principal phenomena affecting the dynamics of plasmas. To an ever increasing extent, advances in confinement result from some new insight into the theoretical properties of a particular confinement configuration. And, there is a clear definition of the major remaining theoretical unknown—energy losses due to localized disturbances within the plasma—although the scientific tools to understand these phenomena are not yet in hand.

Plasma Physics – More than 99 percent of the matter in the universe—the sun, the stars and galaxies, plus the material found in interstellar space—is in the form of plasmas similar to those found in fusion devices. One of the most significant contributions to the basic sciences made by fusion research relates to the development of the scientific discipline of plasma physics.

When the MFE Program began in the 1950's, plasma physics—the study of the multiple and complex interactions of charged particles with one another and with their own and other electric and magnetic fields—was in its infancy and being developed primarily by astrophysicists. When fusion researchers encountered inexplicable phenomena associated with magnetically confined plasma fuel in their early experiments, they realized that the development of a fusion reactor would require extension of the infant science of plasma physics. Plasma physics encompasses such fusion relevant topics as plasma equilibrium and stability, confinement, instabilities, turbulence, chaos, and the propagation of particles and radio waves through the plasma.

The broad-based fundamental studies of magnetically confined plasmas over the past two decades have solidified the underpinnings of the relatively new science of plasma physics. Nurtured by the contributions of fusion researchers, plasma physics has since grown to maturity and become the theoretical foundation upon which not only contemporary fusion theory rests, but also modern astrophysics and space physics as well. While plasma physics did not originate in the fusion program, the development of plasma physics into a mature and productive science is a direct product of the fusion effort.

Equilibrium and Stability Theory – Theories prevailing in the 1950's could neither predict nor adequately explain the unexpected phenomena resulting from early attempts to confine plasma fuel within a magnetic field and heat it to fusion conditions. The primary uncertainties revolved around efforts to confine the plasma to the initial shape desired and then to contain its heat as the plasma nears fusion conditions.

Pioneering advances in plasma theory by fusion researchers have explained the early laboratory phenomena and provided much of the basic understanding needed to optimize