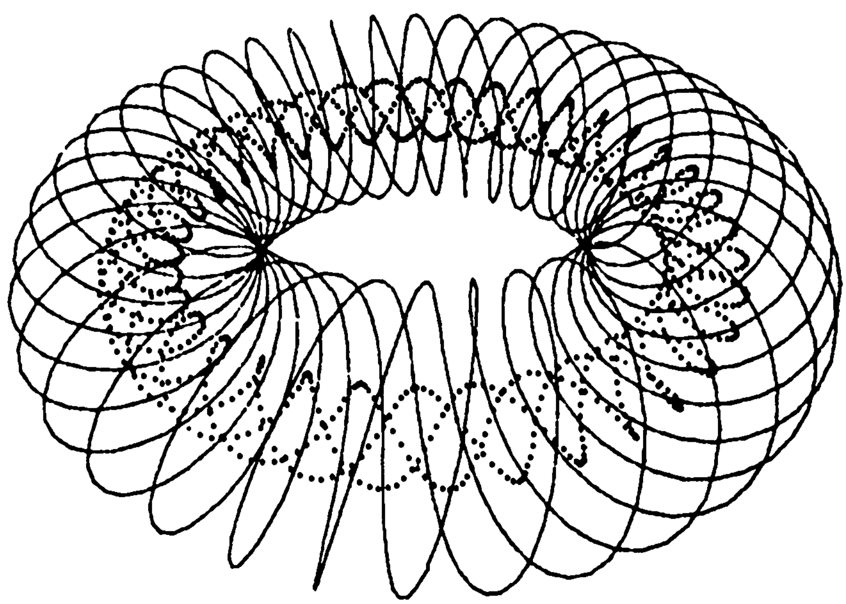
MAGNETIC FUSION RESEARCH



University of California

H. RALPH LEWIS

KENNETH B. FREESE

LOS ALAMOS SCIENTIFIC LABORATORY
Post Office Box 1663 Los Alamos, New Mexico 87545

Magnetic Fusion Research at the Los Alamos Scientific Laboratory

by

H. Ralph Lewis and Kenneth B. Freese

Introduction

An urgent task facing the United States and other countries is to develop a universal source of energy that is nearly inexhaustible yet ecologically desirable. It is imperative that we reduce our dependence on fossil fuels. For example, we are approaching a crisis regarding the use of oil as a major energy source: within the next several decades, the current rate of consumption would exhaust the known worldwide reserves of oil available from wells. Among the several conceivable energy alternatives, one which appears to meet the requirements of nearly unlimited supply and environmental safety is controlled thermonuclear fusion. However, to develop controlled thermonuclear fusion into a practical energy source will require an unprecedented degree of scientific and technological inventiveness.

There are two general approaches toward controlled thermonuclear fusion being studied; they are known generically as magnetic confinement and inertial confinement. The inertial confinement approach uses intense beams of atomic particles or laser light that quickly compress and heat a high density fusion fuel. The magnetic confinement approach uses strong magnetic fields to confine a lower density fuel while energy is released at a slower rate. The Controlled Thermonuclear Research (CTR) Division of the Los Alamos Scientific Laboratory (LASL) participates in national and international programs to explore methods of harnessing the enormous amount of energy potentially available from magnetically confined thermonuclear fusion.

Thermonuclear fusion research began in the early 1950s in the United States, Great Britain and the Soviet Union. From the beginning, LASL has made significant contributions to this research and continues to play an important role now. For example, the first successful laboratory experiments to produce thermonuclear reactions were done at LASL in 1958. During the 1960s and 1970s considerable progress was made throughout the world in magnetic confinement research. In the last decade, the so-called tokamak concept has emerged as the most promising approach for designing the first fusion reactor. At LASL, the emphasis in magnetic confinement research is on two other concepts, the reversed field pinch (RFP) and the compact toroid (CT). These concepts are possible alternatives to the tokamak. It is important to study alternatives because, despite current optimism regarding the tokamak approach, there are still serious obstacles that must be overcome before a practical tokamak power reactor can be built. LASL is also contributing to some aspects of tokamak research, and is studying various problems in reactor engineering, tritium handling, and materials science. By so doing, LASL is contributing to the general field of fusion reactor design.

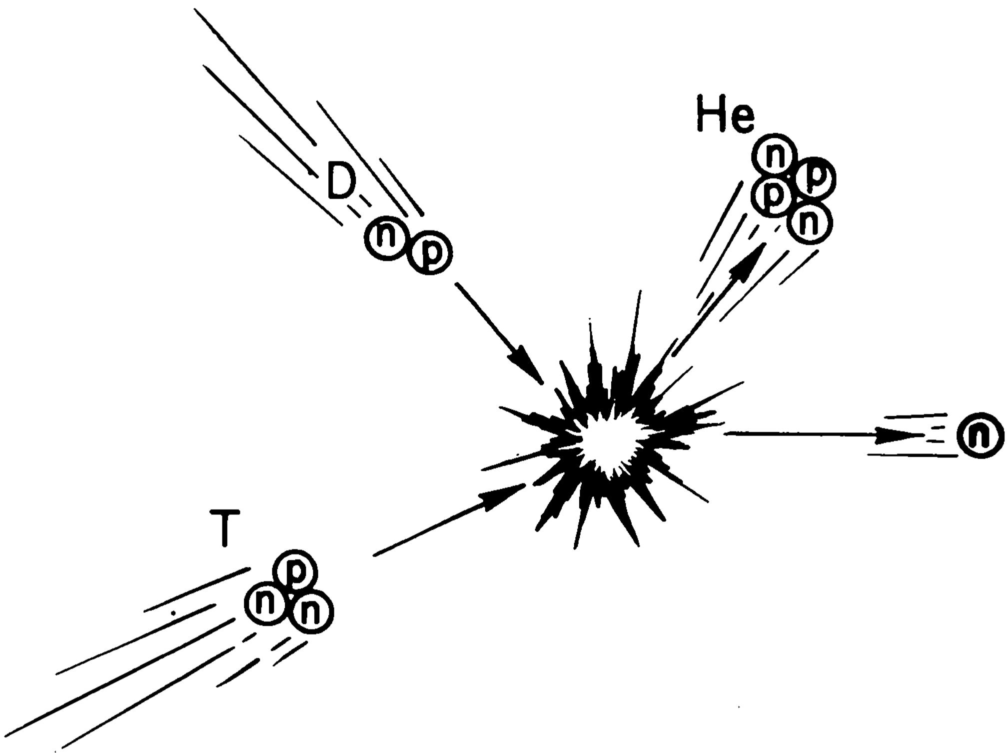
Scientific Background

Nuclear fusion occurs naturally within the sun and other stars, producing the vast amount of energy which is radiated. Under these conditions of extreme temperature and pressure, the light atomic nuclei of the sun's interior collide and fuse together, forming different nuclear species. This thermonuclear fusion process also converts some of the mass of the colliding nuclei into energy according to Einstein's mass-energy relation, $E = mc^2$. The energy released from each fusion reaction is typically over one million times greater than the energy released per chemical reaction when carbon-based fuels are burned. Utilizing the enormous amount of energy available from thermonuclear reactions is the goal of the controlled thermonuclear research (CTR) program.

In a practical fusion reactor, the fuel must be heated to very high temperatures, in the range of 100 million degrees Celsius, and it must be confined long enough for the total energy produced by the fusion reactions to exceed the energy required for operating the reactor. At these high temperatures, the gaseous fuel, which is called a plasma, consists of positively charged atomic nuclei and negatively charged electrons. High temperature is required in order that typical speeds of the nuclei in the plasma will be large enough to overcome the electrostatic repulsion that tends to prevent fusion reactions from occurring. However, at such temperatures, the walls of any material container would disintegrate, and the wall material would then mix with the plasma, quenching the fusion process. Therefore, while the fusion reactions are in progress, contact of the plasma with material walls must be inhibited. Inertial confinement schemes seek to satisfy this requirement by heating a fuel of such high density that the confinement time required is shorter than the time it would take for the hot plasma to expand to the walls of the containment vessel. Magnetic confinement uses magnetic fields to hold a much lower density fuel away from the container walls. The various schemes for magnetic confinement all rely on magnetic forces that tend to oppose expansion of a plasma across a magnetic field. A major goal of magnetic confinement research has been to devise magnetic field configurations in which a hot plasma can be confined away from container walls for a long enough time to be useful in a fusion reactor. No magnetic confinement scheme is completely effective, but much progress has been made in understanding the very complex processes that determine how long a hot plasma can be confined. The prospect is good that in this century a magnetic confinement scheme will be demonstrated to be adequate for a fusion reactor.

Fusion Fuel

The most promising fuel for the first fusion reactor is a mixture of deuterium (D) and tritium (T), which are heavy isotopes of hydrogen. The atomic nuclei of these elements are called deuterons and tritons, respectively. The fusion of a deuteron and a triton, known as a D-T reaction, yields an alpha particle, a neutron, and a large amount of energy.



$$D + T \longrightarrow He + n + 17.6\ MeV$$

An alpha particle is the atomic nucleus of the naturally occurring isotope of helium; a neutron is an electrically neutral particle which, like the proton, is a fundamental constituent of atomic nuclei. The energy that is released as a result of a D-T fusion reaction is in the form of kinetic energy (energy of motion) of the alpha particle and neutron. In a reactor, an extremely important use of some of the energy of the alpha particles would be to heat the unreacted fuel in order to maintain the conditions required for sustained burning; the situation in which the alpha particles make the fuel hot enough to continue burning on its own is known as <u>ignition</u>. Another use of some of the alpha particle energy is direct conversion of the kinetic energy into electrical energy; this is possible because the alpha particles are electrically charged. The kinetic energy of the neutrons in a reactor would be absorbed by lithium (Li) contained in a blanket of material surrounding the reactor. Absorption of that energy would heat the blanket; then the heat would be taken from the blanket by a circulating coolant and converted to electrical energy with conventional turboelectric generating machinery. As the high-energy neutrons heated the lithium, they themselves would undergo fusion reactions with the lithium nuclei. This neutron-lithium reaction yields, among other products, a triton. The tritium produced by this reaction would be collected and recycled into the reactor as fuel.

Deuterium atoms occur naturally in water, in which atoms of ordinary hydrogen are sometimes replaced by atoms of deuterium; atoms of ordinary hydrogen, deuterium, and tritium are chemically identical. For every 6500 atoms of ordinary hydrogen in naturally occurring water, there is one deuterium atom. It is estimated that this amounts to about 100 trillion (10^{14}) tons of deuterium in the oceans, lakes and rivers of the world. Deuterium for fusion reactors could be obtained easily and economically from this enormous supply; the supply is practically inexhaustible. In contrast to deuterium, tritium is radioactive and does not occur naturally. However, it would be readily available for fuel because it would be produced as a byproduct of the neutron-lithium reaction in the reactor blanket. The radioactivity of tritium does not pose a long-term problem because the halflife for its decay is only 12.4 years. Methods for dealing with the short-term hazard due to the radioactive decay of large quantities of tritium are being investigated at LASL. At present there is no shortage of lithium that would be needed for absorbing neutrons in the reactor blanket. Projections indicate adequate U. S. lithium resources to sustain an economy based on fusion power for more than a century. If availability of lithium were to become a problem, recovery from the oceans would be an expensive but not impossible alternative. The lithium contained in sea water is estimated at over 10 trillion (10^{13}) tons. Further in the future, researchers hope to design and build an advanced fusion reactor that would not burn tritium and would not produce neutrons that must be absorbed.

Advantages

A pure fusion reactor would have advantages in comparison with a fission reactor. There are advantages with regard to the problem of radioactive wastes. The nuclear fission process produces energy by splitting the nuclei of heavy atoms like uranium or plutonium. Some of the fission products are radioactive with extremely long halflives. Ways must be found to handle and store these radioactive wastes for thousands and, in some cases, hundreds of thousands of years. By contrast, the only direct radioactive product in a D-T fusion reactor would be tritium, which would be recycled for use as fuel. Because of its short halflife, tritium would not pose a long-term radioactivity hazard. The structural material of a fusion reactor would become radioactive due to bombardment by neutrons; however, this also occurs in fission reactors. The total radioactivity generated by a fission reactor power plant is greater than, and lasts longer than, the radioactivity of an equivalent fusion reactor power plant. A fusion reactor would also be very advantageous in that there would not be a possibility of a core meltdown, a runaway reactor, or a nuclear explosion. The reason is that there would be only a very small amount of fuel in the reactor at any time.

LASL Magnetic Fusion Experiments

During the next decade, large tokamak devices now under construction throughout the world are expected to reach ignition conditions using a deuterium-tritium mixture as fuel. Near the end of that period, construction may begin in the United States on an Engineering Test Facility (ETF) designed to move the national magnetic fusion energy program from applied research into a strong development phase. The ETF would be an integrated system that could produce electrical power and also establish the engineering requirements for each of the major components of a prototype fusion reactor. Yet tokamaks, for all their promise, possess some disadvantages as practical reactor systems. For this reason, the national magnetic fusion energy program supports parallel development of advanced fusion concepts which might avoid these disadvantages. The majority of the LASL CTR effort is devoted to the study of two such advanced concepts.

One of these is the reversed field pinch (RFP) approach to confinement. The RFP is a toroidal, or doughnut shaped, magnetic confinement system, somewhat related to the tokamak, which may avoid some of the difficulties of tokamaks. In particular, the RFP has the potential of heating the plasma to ignition temperatures using ohmic heating; i.e., the electrical currents within the plasma heat the plasma in the same manner as they heat the heating element in an electric toaster. Presently, tokamaks must use some form of auxiliary heating to attain ignition. Furthermore, an RFP reactor could be less complex and more economical to operate than a tokamak reactor. Two RFP devices are in operation at LASL: the ZT-40 device, which was completed late in 1979, and a smaller device known as ZT-S. The ZT-40 experiment is expected to attain operating temperatures in the range of several million degrees Celsius and reach confinement times greater than 200 millionths of a second. It should represent a significant step toward demonstration of the feasibility of the RFP concept for a fusion reactor.

The second advanced fusion concept being studied in the LASL CTR program is the compact toroid (CT) configuration. The compact toroid is similar to the tokamak and RFP in that it also uses a toroidal magnetic field configuration. The major difference is that the external vacuum vessel is not toroidal, and material walls do not pass through the center of the plasma torus. This allows the hole in the plasma torus to become very small, producing a compact toroidal shape. Another difference between the compact toroid and both the RFP and tokamak devices is that the confining magnetic field is generated completely by electrical currents that flow within the plasma; no currents are required in external conductors once the plasma is formed. An important consequence is that a reactor design may be possible that represents a considerable simplification and improvement over either tokamak or RFP reactor designs. With the compact toroid configuration, it may even be possible to consider advanced fuels that do not use tritium or involve lithium. A large compact toroid experimental facility (CTX) has been completed at LASL, and initial experiments began in the spring of 1980.

ZT-40 FACILITY

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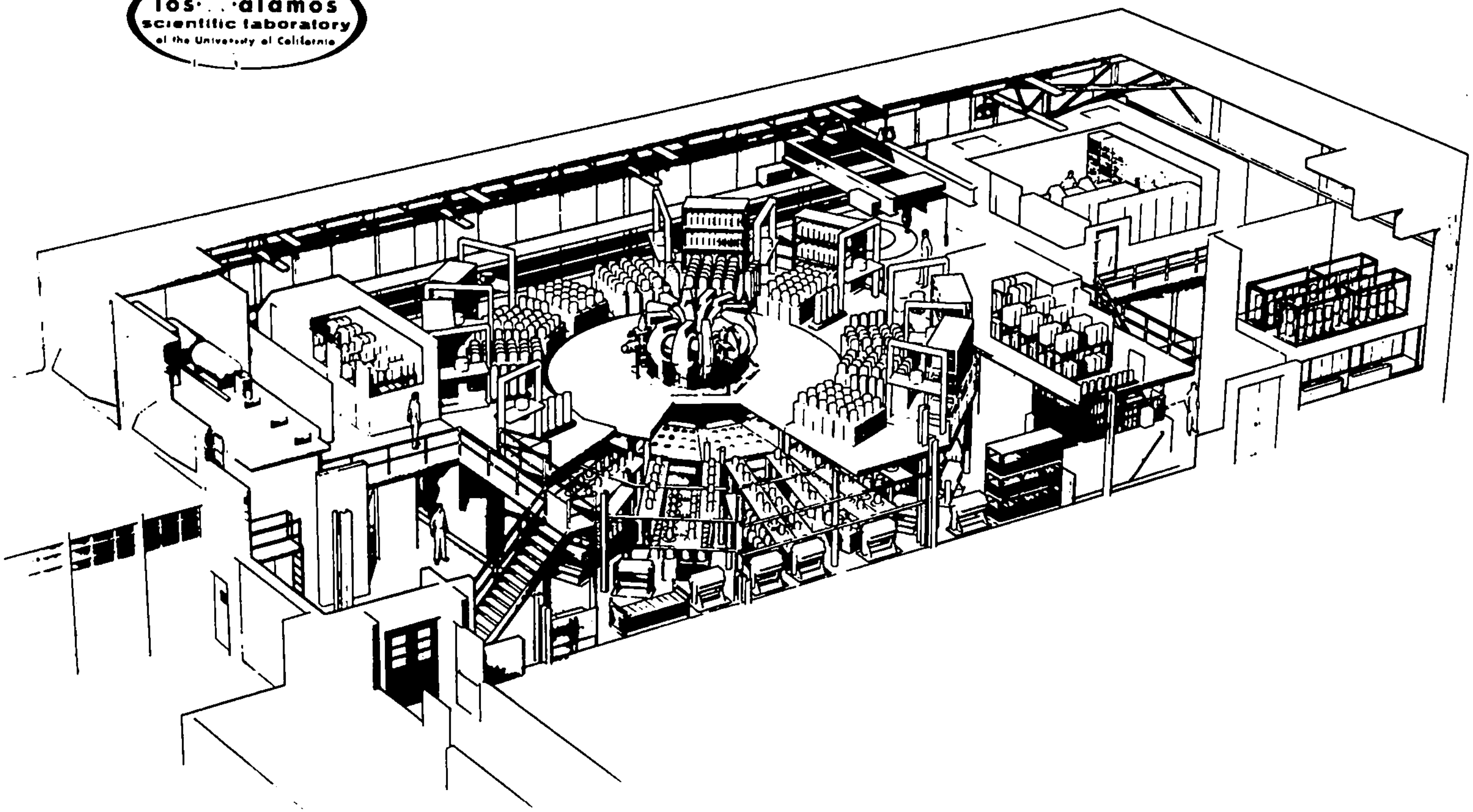

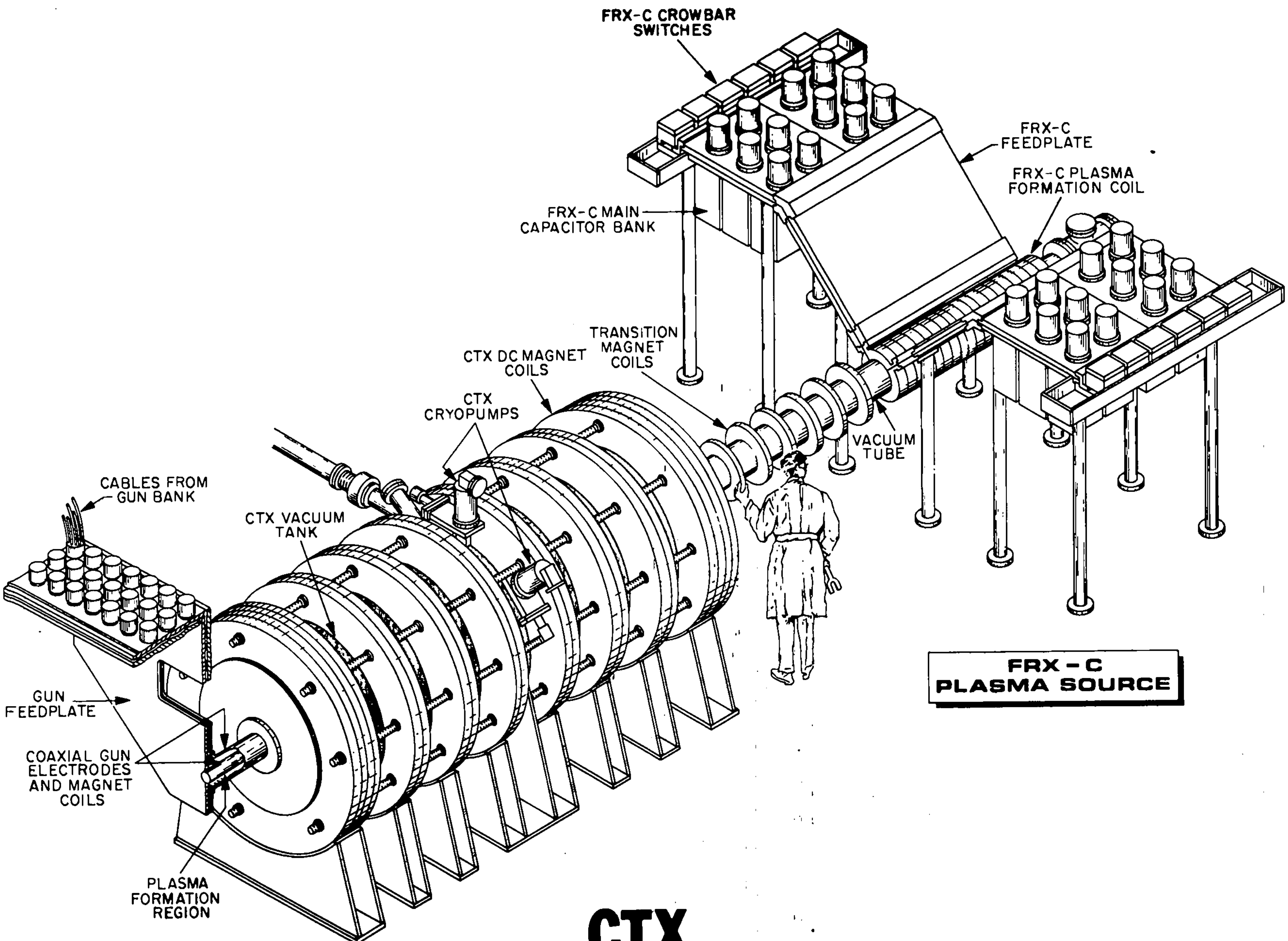

CTX FACILITY

A large part of the experimental effort in the LASL CTR program is directed toward developing diagnostic techniques and instrumentation that are used to measure plasma properties such as temperature, density, and magnetic fields. Many measurements are performed routinely and automatically during the experiment. For understanding the details of plasma behavior, large fusion experiments require many diagnostic measurements. These measurements generate such copious amounts of data that the use of computers for data acquisition, analysis, and storage has become an absolute necessity. Computers are also needed to monitor and control the complicated electrical and mechanical systems of a large experiment. Both ZT-40 and CTX are experimental facilities that rely on computers for control, data acquisition, and online data analysis.

The RFP and CTX confinement experiments are also supported by a vigorous program in theoretical and computational plasma physics. The purposes of the theoretical and computational research are to develop methods for describing and predicting experimental results, and to apply those methods to actual experiments. This work is a very important ingredient of the total research effort.

Engineering and Technology

There are programs at LASL that develop engineering technology common to all fusion reactor designs. A magnetic fusion systems studies program assesses the engineering aspects of conceptual designs of proposed fusion reactor systems. The purpose is to anticipate and help solve the problems associated with designing and constructing an electric power plant based on fusion energy. In direct support of the national tokamak program, LASL is developing large superconducting magnetic field coils for use with large tokamak devices in the future. Also, the Tritium Systems Test Assembly (TSTA) will be used to demonstrate a complete D-T fuel cycle under conditions similar to those expected in a fusion reactor, including practical methods for dealing with the short-term radioactivity hazards associated with handling large quantities of tritium. TSTA will begin operation at the end of 1981. Finally, there is a program at LASL that develops insulators and ceramic materials for use in fusion reactors, a program for studying radiation damage in materials under conditions that simulate a fusion reactor, and a program that studies neutron and gamma-ray transport as it applies to fusion reactors.

In Conclusion

The Los Alamos Scientific Laboratory is actively contributing to the national magnetic fusion energy program, not only by investigating advanced fusion concepts that may be alternatives to the tokamak, but also through direct support of the tokamak effort itself. Historically, LASL was a pioneer in controlled thermonuclear research and now it is continuing in national and international efforts to utilize the great potential of fusion energy for the benefit of mankind.

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