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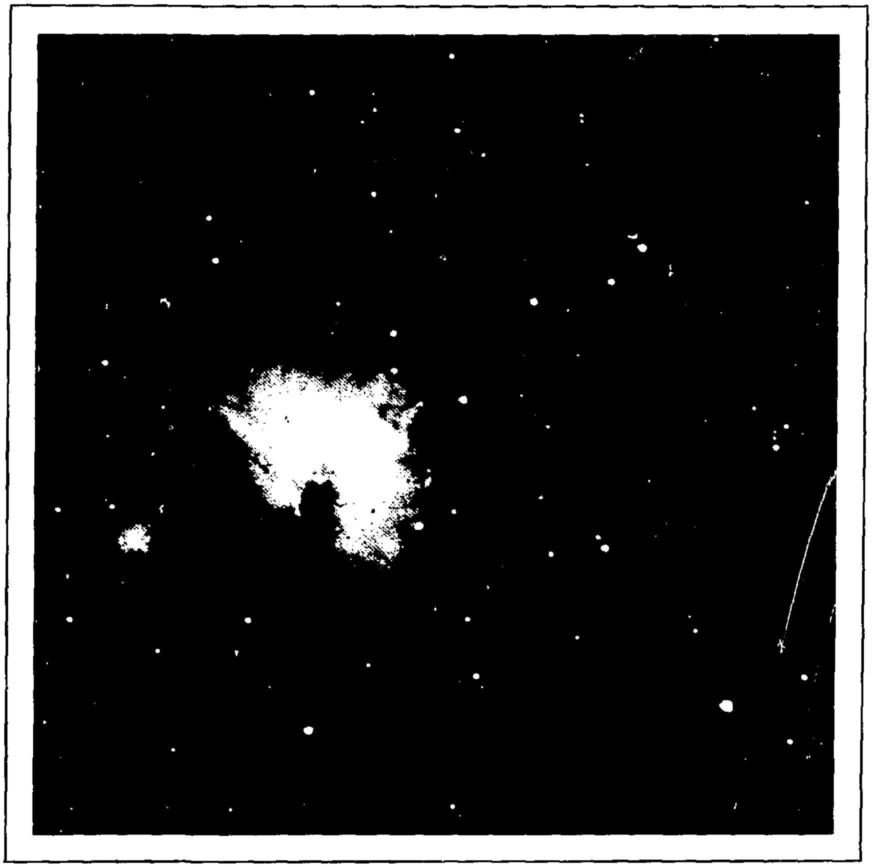
FUSION ENERGY

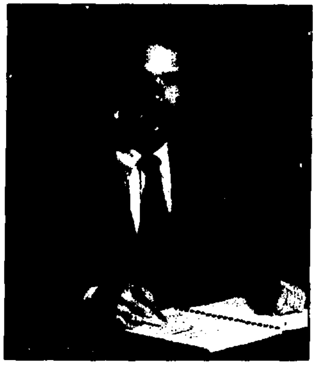
AND CANADA'S ROLE



Canadian Fusion Fuels Technology Project

CFFTP

Cover photo: *The great nebula in Orion. Twenty-five light years across, fifteen hundred light years away. The nebula, a great mass of hydrogen gas, is illuminated as new stars are formed when the fusion process is initiated in the stellar cores.*



Fusion is the process of releasing energy from matter which occurs in our sun.

Canada is contributing to the development of technology which will permit this process to be harnessed and made available on earth. The international effort has increased from a modest beginning in the 1950s to a level of approximately two billion dollars annually in the 1980s.

The purpose of this booklet is to introduce the concept of fusion energy as a technology which should make an important addition to the mix of energy sources for our future. Through a co-ordinated approach, Canada has established several projects which will contribute significantly to the development of technologies in specific areas leading to opportunities now for Canadian industry in the international effort. We, at the Canadian Fusion Fuels Technology Project, are proud to be part of this effort.

Dr. T. S. Drolet,
Program Manager

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WHY FUSION ENERGY?

The uncertain state of our future energy resources has prompted technologically advanced countries to search for alternatives. These alternatives must not only be a substitute for the old but also should be improvements in diverse ways: they should offer long term reliability, be gentle with the environment and generally offer the possibility of a better society. One resource which has the potential to fulfill these requirements is fusion energy. Canada is taking a significant and unique part in the development of this advanced technology.

Many of the resources we have depended upon in the past are becoming less viable sources of energy. Oil is one such resource. Approximately one-half of all the conventional oil reserves "Spaceship Earth" started out with have been used, and in the next few decades the remaining half will be quickly used. At present, our non-conventional reserves are uneconomical to recover. Oil has actually been a fleeting phenomenon in the history of industrial society, but it has been responsible for determining the type of technological society we have.

We have become a very mobile people; we do not have to live within walking distance of our place of work as most people did in the last century. Portable, high energy-content liquid fuels have made the motorcar not just a luxury but almost a necessity, and the fuel it uses comes from oil.

Many of us live in comfort, in climates that in bygone times supported only subsistence societies. The heat we require for this comfort comes largely from the burning of oil and gas.

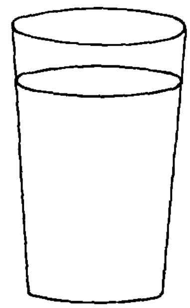
The food we eat, in all likelihood, was grown in highly fertilized soil; the fertilizer was probably made using natural gas. It has been suggested that a definition of modern agriculture is "a process of transforming oil into food". All of these things, and countless others which permit our society to exist, are a result of our ability to find and exploit energy resources.

With reduced emphasis on oil as an energy resource during the next 50 years, the search is on for a long-term replacement. It must satisfy our requirements for a reasonable maintenance of our standard of living, it must extend that standard to the Third World, and it must be consistent with our recently awakened sensitivity to the fragility of our environment.

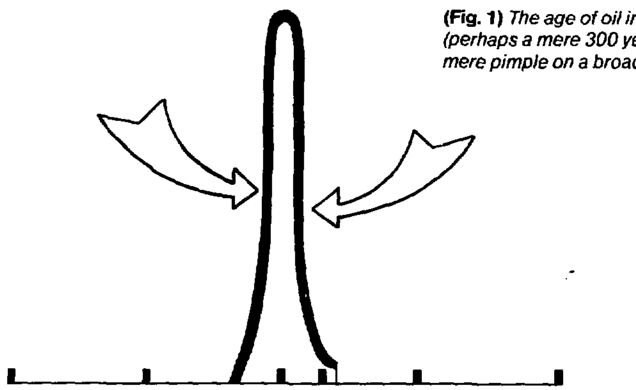
The choice will not be an easy one; in fact there will not be a single choice. Our future energy systems will undoubtedly be a complex mix of various energy sources. Wind, geothermal, tidal, biomass and solar energy systems are all under active research today and are capable of making a small but useful contribution to our future energy requirements.

Nuclear energy from uranium fission reactions has been seen as the logical alternative to fossil fuels for the generation of electricity. In recent years some segments of the public have questioned total reliance on this technology, and its development has had a troubled career. Nevertheless, nuclear fission energy will remain as a logical and increasingly significant contributor to our electricity-production system until a new energy system appears in the future.

Scientists and engineers think they know what this alternative will and must be. When it comes to fruition, surely **Fusion Energy** will be one of the greatest scientific and technological achievements of mankind.



(Fig. 2) *One glass of tap water contains enough hydrogen to represent a potential fusion energy equivalent to the energy of 600 000 litres of gasoline.*



(Fig. 1) *The age of oil in which we live (perhaps a mere 300 years) appears as a mere pimple on a broad time scale.*

FUSION – WHAT IS IT?

The aim of fusion technology is to control, on earth, the same energy source that powers our sun and the stars. Unfortunately, what the sun manages to do is proving to be one of the greatest intellectual and technical challenges man has ever faced. Energy is produced in the sun by nuclear reactions, but these should not be confused with the nuclear energy processes in uranium fission reactors. All nuclear energy, both fission and fusion, is described by Albert Einstein's (1879-1955) famous equation published in 1905:

$$E=mc^2$$

This equation expresses the basic principle that mass "m" may be completely converted into an equivalent amount of energy "E". (The reverse is also true – energy may be converted into mass.) In the equation, "c" is the velocity of light – a very large number (c=300 000 000 metres per second). Thus a small amount of mass produces a very large amount of energy. For example, if one sugar cube (mass = 1 gram) could be entirely converted into energy it would produce the same energy as burning 2.7 million litres of gasoline!

There are certain large atomic nuclei, like uranium, which can be induced to break apart into two or more pieces. The total mass of the pieces is slightly less than the mass of the original nucleus. This "mass defect" appears as energy according to Einstein's equation. This is the process which operates, in a controlled way, in a fission reactor.

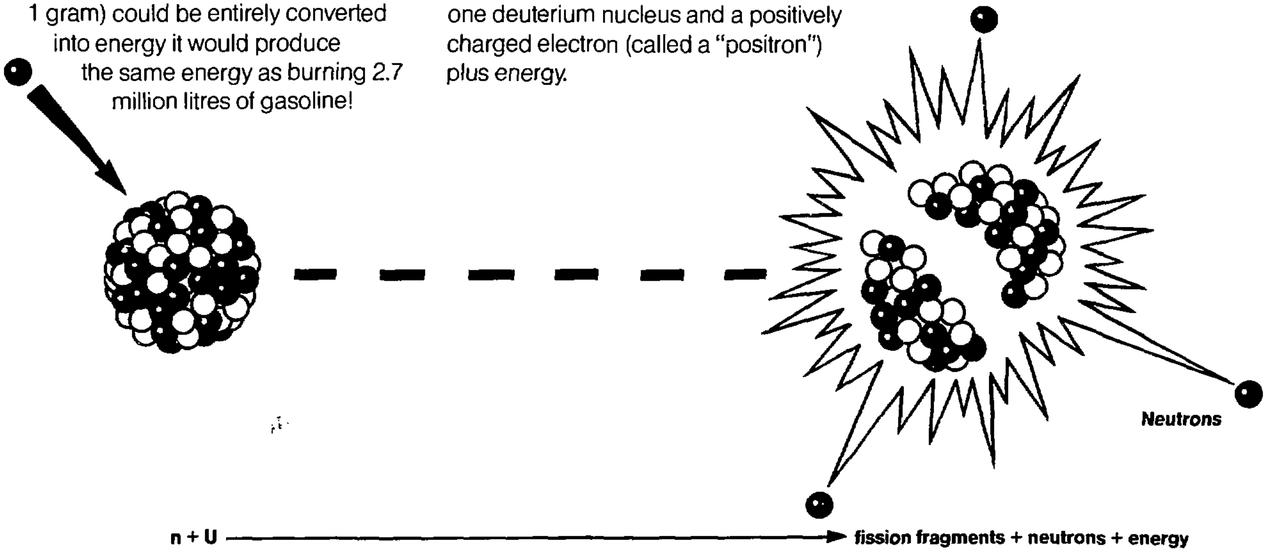
At the other end of the mass scale, very light nuclei can be combined or fused together. The resulting single nucleus has less mass than the original nuclei. Again the mass defect appears as energy. All the light elements up to the mass of iron can undergo fusion reactions and produce energy. In certain stars all of these fusion reactions do take place; however, only the lightest elements, hydrogen, helium and lithium have a chance of fusing under conditions we might produce on earth.

By far the most prevalent fusion reaction in the sun is:

$$H + H \rightarrow D + e^{+} + \text{Energy.}$$

This equation simply says that two hydrogen nuclei fuse together to form one deuterium nucleus and a positively charged electron (called a "positron") plus energy.

What are the conditions under which such a reaction might take place? There are four basic forces in nature: gravitational, electrical and two forces associated with particles in the nucleus of atoms. The gravitational and electrical forces act over distances which are large compared with the dimensions of atoms. Nuclear forces, however, have a very short range. This means that two nuclei must be brought very close together before the nuclear attraction will fuse them. Both nuclei carry positive electrical charges and, since like charges repel, it is difficult to get the two nuclei together. Two things will help: high pressure will force the nuclei



(Fig. 3) *The fission reaction uses neutrons to split a heavy atom, such as uranium, into smaller atoms, with the release of energy and more neutrons.*

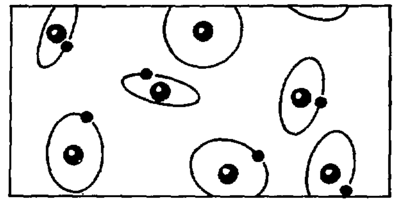
together and high temperature will give the nuclei such high speeds that some, in a head-on collision, will get very close to each other.

The sun is particularly good at producing high pressure in its central regions because of the gravitational field of its very large mass. Along with the high core temperature, the sun can carry out the H + H (so-called "proton-proton") reaction very easily. It is the major energy producing process in our sun and in most stars. But it will be a long time before we make it work as a practical source of energy on earth!

The problem is that the pressures in the centre of the sun are simply not achievable in large machines on earth

Solid, Liquid, Gas, and **Plasma**

If the temperature of a gas is raised sufficiently, the atoms in the gas will collide with sufficient energy to remove their outer electrons (see box on the hydrogen family). This will result in a high-temperature medium consisting of positively charged ions and negatively charged electrons, whose overall electrical charge is still neutral. This swirling cloud of charged particles is a state of matter called a plasma.

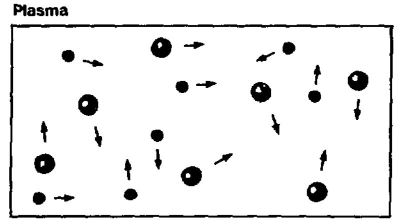


Gas

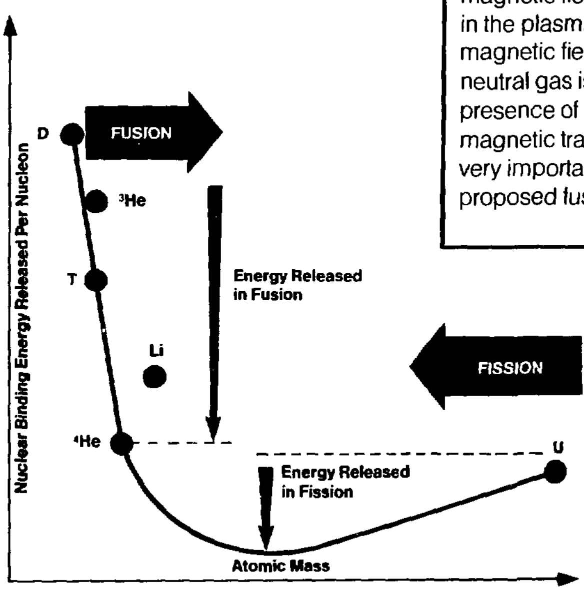
Such a plasma has quite different properties from the gas out of which it was made. For example, the plasma is a very good conductor of electricity because of its free electrons and ions, whereas the gas it was made from may have been a very poor conductor. It is also a good heat conductor, while gases are generally poor in this respect. If a magnetic field is present the particles in the plasma will be trapped on the magnetic field lines, whereas the neutral gas is largely indifferent to the presence of a magnetic field. The magnetic trapping of the plasma is very important in a large class of proposed fusion machines called "magnetic confinement" devices.

Plasma has often been called "the fourth state of matter". It is not, in fact, a rare state. It exists only for a short time on earth in such diverse places as lightning discharges or inside fluorescent light fixtures, but stars are made up largely of matter in the plasma state. The northern lights also are the result of charged particles from the interplanetary plasma travelling into the earth's atmosphere along its magnetic field lines.

Plasma



(Fig. 4) *The energy released in both fission and fusion reactions was previously contained as the binding energy of the nuclei involved in the reactions.*



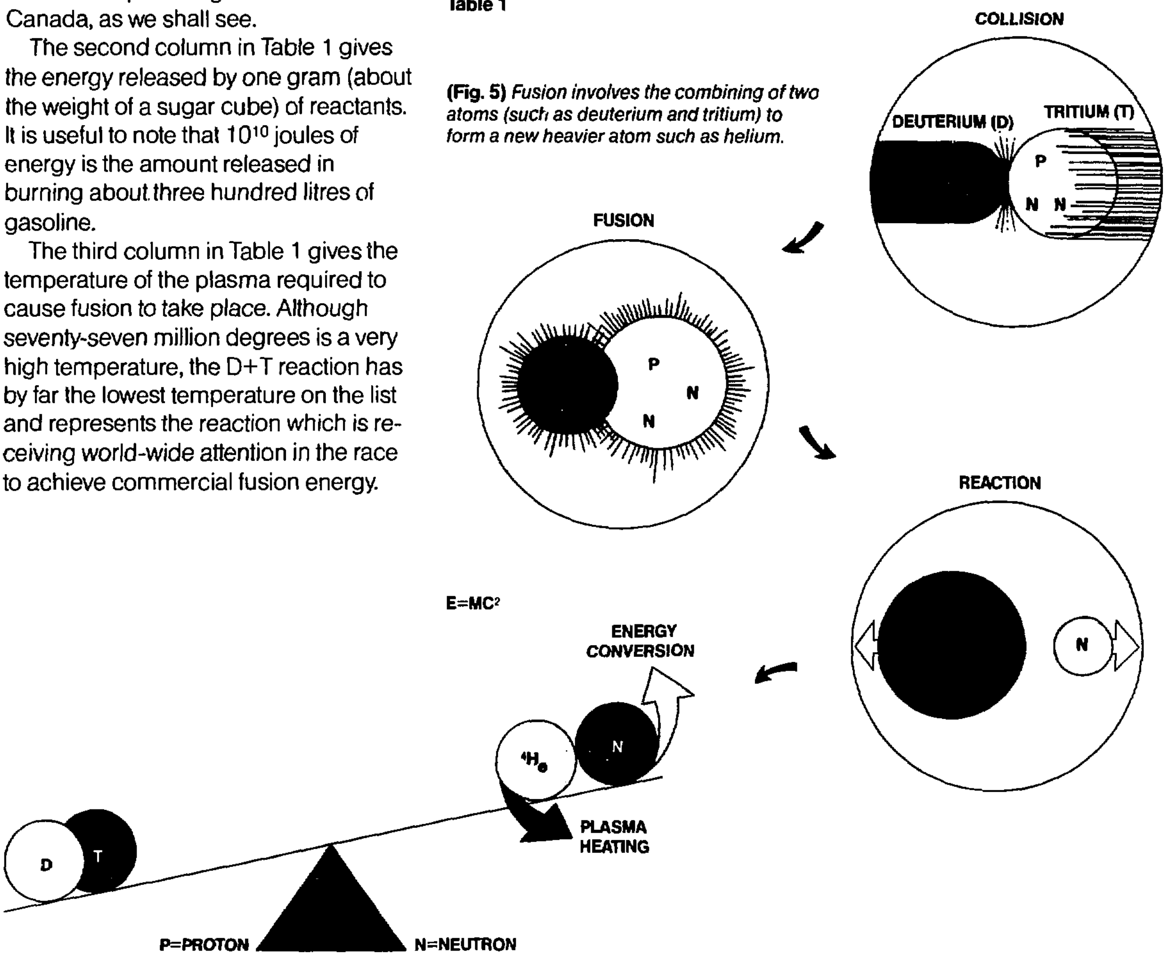
and so we must establish fusion conditions with high temperature alone. Fortunately, there are several fusion reactions which have less stringent requirements than the reactions in the sun; these are listed in Table 1. Of these, the first three are the most interesting. None of these reactions involves normal hydrogen, but relies instead on the heavier isotopes deuterium (D) and tritium (T). The first three reactions involve only these, a fact which has special significance for Canada, as we shall see.

The second column in Table 1 gives the energy released by one gram (about the weight of a sugar cube) of reactants. It is useful to note that 10^{10} joules of energy is the amount released in burning about three hundred litres of gasoline.

The third column in Table 1 gives the temperature of the plasma required to cause fusion to take place. Although seventy-seven million degrees is a very high temperature, the D+T reaction has by far the lowest temperature on the list and represents the reaction which is receiving world-wide attention in the race to achieve commercial fusion energy.

FUSION REACTION	ENERGY IN JOULES PER GRAM OF REACTANTS	IGNITION TEMPERATURE IN MILLIONS OF DEGREES C
$D + T \rightarrow {}^4He + n$	16.9×10^{10}	77
$D + D \rightarrow {}^3He + n$	4.0×10^{10}	773
$D + D \rightarrow T + p$	4.8×10^{10}	386
$D + {}^3He \rightarrow {}^4He + p$	17.7×10^{10}	620
$D + {}^{10}B \rightarrow 3\,{}^4He$	3.2×10^{10}	2300

Table 1



(Fig. 5) *Fusion involves the combining of two atoms (such as deuterium and tritium) to form a new heavier atom such as helium.*

THE HYDROGEN FAMILY

All atoms which make up the universe are themselves constructed of three basic particles:

Proton (p): a positively charged particle,

Neutron (n): a particle with almost the same mass as the proton (it is 0.16% heavier) but with no electric charge,

Electron (e): a light particle (it takes 1836 e's to equal the mass of one p) which has an electric charge equal to that of the proton but of opposite (or negative) sign.

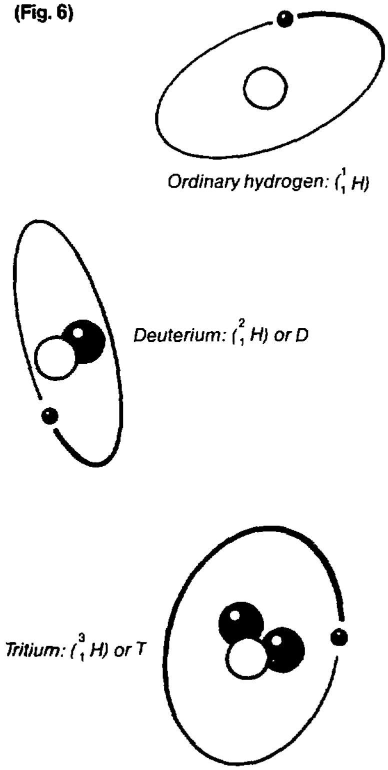
Since atoms are electrically neutral it follows that atoms must contain an equal number of protons and electrons. The simplest possible atom consists of one proton and one electron; such an atom is called "hydrogen". The proton forms a massive "nucleus" and the light electron may be thought of as orbiting in a much larger space outside the nucleus.

The chemical properties of this atom are entirely determined by the outer electron, but there is another "hydrogen" which has as its nucleus a combination of one proton and one neutron. This is heavy hydrogen or "deuterium"; chemically, it is still the same as hydrogen, since it has only one orbiting electron. Thus it forms "heavy water" or D_2O just as ordinary hydrogen forms normal water or H_2O when it reacts chemically with oxygen. On earth, the natural occurrence of deuterium is one part in seven thousand of ordinary hydrogen.

A third type of hydrogen may be obtained by adding a further neutron to the nucleus; this is "triple heavy hydrogen" or "tritium". Here, however, we have exceeded the limits of nuclear stability and the atom is radioactive, one of the neutrons undergoes a transformation into proton + electron, and since the electron cannot remain inside the nucleus it is expelled as a beta particle.

The resulting nucleus is that of helium (^3He). The half-life of this process is about twelve years, that is, in a given sample of tritium, half of the atoms will decay in twelve years, half of the remainder in a further twelve years and so on. Although tritium does not occur to any great extent naturally, it is produced in fission reactors by the bombardment of heavy water by neutrons.

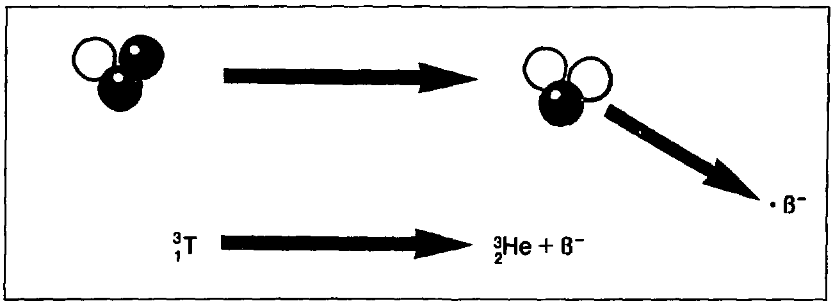
(Fig. 6)



Ordinary hydrogen: (^1_1H)

Deuterium: (^2_1H) or D

Tritium: (^3_1H) or T



Tritium decays with a half-life of about 12 years into helium–3, accompanied by the emission of a β^- particle.

THE CHALLENGE OF PLASMA CONFINEMENT

In an operating fusion reactor the required plasma temperature must be so high that just keeping it confined is a major problem. It is not that the plasma will melt the container (it doesn't contain enough total heat energy for that), it is just that any contact of the plasma with a material container will cool the plasma. The fusion plasma must be either held in a non-material container, or the fusion process must be completed so quickly that it does not have sufficient time to lose heat to its surroundings.

There are three types of confinement: gravitational, magnetic and inertial.

Gravitational Confinement is what the sun and stars do and presently appears to be impossible for man to duplicate.

Magnetic Confinement is the method which has been pursued continuously since the 1950s and shows high promise for a demonstration of fusion energy breakeven in the near future. The method depends on the fact that an electrically charged particle in motion will travel along a line of magnetic field or spiral around it in a corkscrew fashion. The aim, then, is to trap the plasma in a suitably shaped magnetic field, away from the container walls, for a sufficiently long time. During this time the temperature and density of the plasma can be built up so that fusion can take place.

Magnetic confinement schemes tend to be unstable and the plasma can be confined for only a certain time. If this time is very short, then the density of the plasma must be high in order to achieve a sufficient number of reactions so that more energy is produced than was required to create the plasma. If the confinement time can be made longer, then the required density may be lower, and still produce the same number of collisions. This relation is expressed as the "Lawson Criterion".

For a two hundred million degree plasma, the product of the density (in particles per cubic centimetre) and the confinement time (in seconds) must be greater than about $10^{14}cm^{-3}s$. Thus, at a density of 10^{14} particles per cubic centimetre ($10^{14}cm^{-3}$), the plasma energy must be confined for about one second. The requirements of temperature and Lawson Criterion have been met separately in different machines, but, as of 1984, not simultaneously in the same plasma.

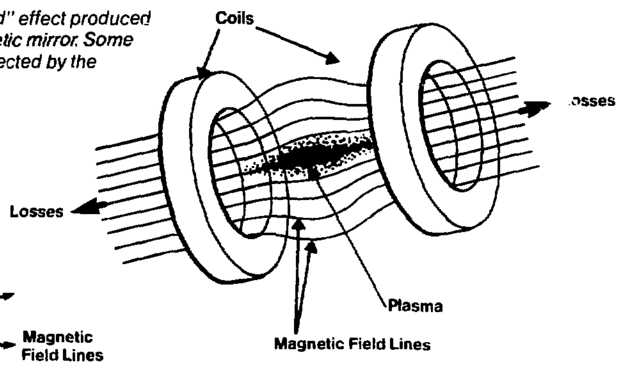
There are two major types of magnetic confinement machines:

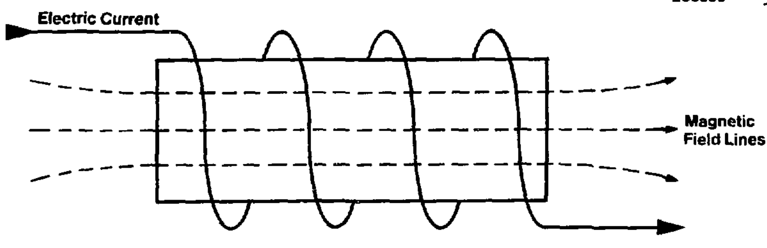
The **Magnetic Mirror** is the simplest magnetic confinement method to visualize. A hollow tube with a helical current-carrying conductor wrapped around it is called a "solenoid" (see Fig. 7). The magnetic field lines of a solenoid run the length of the tube parallel to the axis. A charged particle injected at one end of such a solenoid will travel down the tube and never touch the walls, since it is trapped on the field lines. Unfortunately, it will just pass out the other end and be lost.

If we now increase the number of windings at each end of the solenoid, the field will get "pinched". In fact we can use two coils separated by a gap to produce the same pinched effect (see Fig. 8). The pinching has the effect of reflecting most of the charged particles back into the region of weaker magnetic field between the coils. Thus the plasma is largely confined in the magnetic bulge (sometimes called a "magnetic bottle") between the coils. The whole assembly is called a "magnetic mirror".

Machines of this type have been most

(Fig. 8) The "pinched field" effect produced by an open-ended magnetic mirror. Some charged particles are reflected by the pinched field.





(Fig. 7) *The magnetic field produced by a solenoid.*

intensively investigated at the Lawrence Livermore Laboratory of the University of California.

The **Tokamak** is a machine which attempts to eliminate the end leakage of the plasma in the mirror machine by eliminating the ends. Imagine bending the solenoid of Fig. 8 into a circle and joining the ends so that you have a donut. The proper name for a donut-shape is a "torus" and the word "Tokamak" comes from the Russian words for "torus", "chamber", and "magnetic"; such machines were first built in that country.

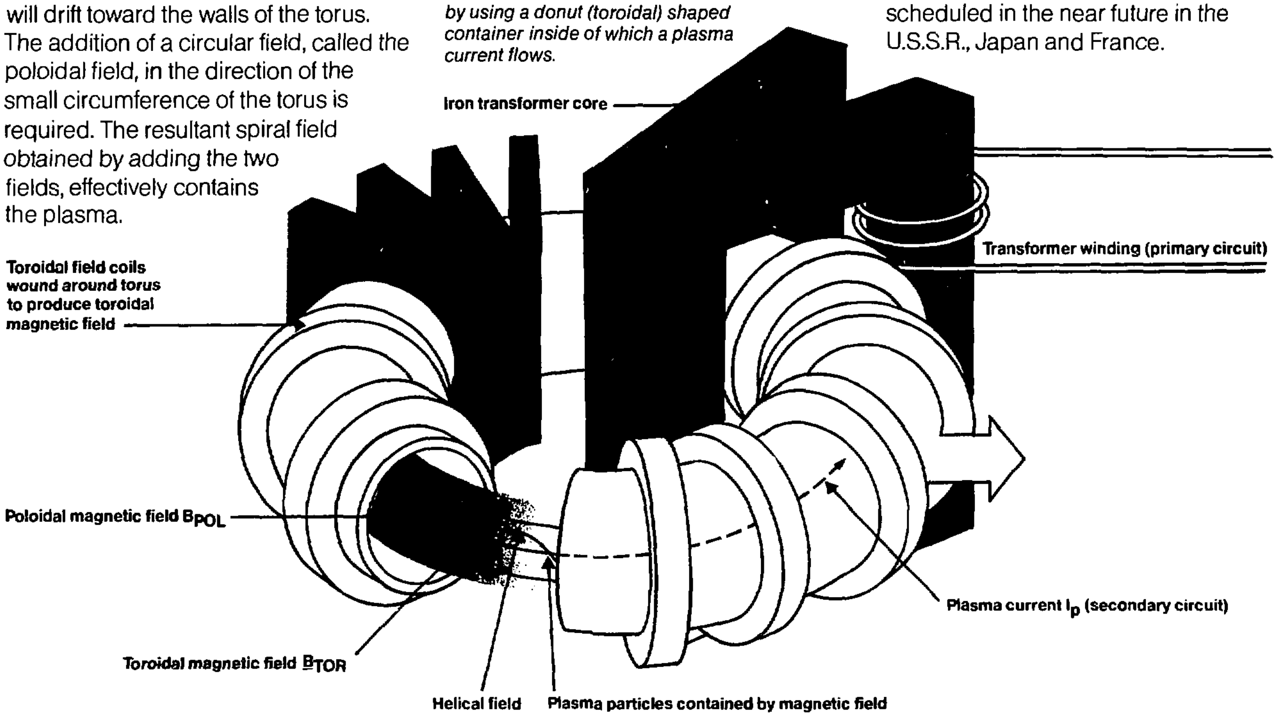
The major elements of the Tokamak machine are shown in Fig. 9. The windings around the torus produce a uniform magnetic field along the axis of the torus. This "toroidal" field alone is not sufficient to contain the plasma, as it will drift toward the walls of the torus. The addition of a circular field, called the poloidal field, in the direction of the small circumference of the torus is required. The resultant spiral field obtained by adding the two fields, effectively contains the plasma.

In the Tokamak, the plasma itself creates the poloidal field. Up to twenty large transformer cores (Fig. 9 shows only two) are linked through the hole in the torus, and, as the current rises in their primary coils, the plasma is driven around in the axial direction in the torus. It acts as the secondary winding of the transformer. This plasma current creates the poloidal field; it also helps to heat the plasma.

The Tokamak can only be operated in pulses because of the transformer action of the poloidal field coils. It must be designed so that during one pulse of the poloidal field the plasma will have sufficient temperature, confinement time and density to produce more fusion energy than is required to operate it.

Various methods are used to raise the temperature of the plasma. In a Tokamak, the current flowing in the plasma heats it just as the current heats a stove element. Heating is also accomplished by the injection of very high speed beams of electrically neutral atoms of deuterium (Neutral Beam Heaters), and by the use of high frequency radio waves (R.F. heaters) like those used in microwave ovens.

Tokamaks are the furthest advanced form of fusion research machines, and have been built in several countries including the U.S.A., Germany, Italy, France, Japan, the U.S.S.R., England and Canada. The largest operating machines are the Tokamak Fusion Test Reactor (TFTR) at Princeton in the U.S.A. and the Joint European Torus (JET) in England. Similar machines are scheduled in the near future in the U.S.S.R., Japan and France.



(Fig. 9) *The Tokamak fusion reactor design achieves desired magnetic field properties by using a donut (toroidal) shaped container inside of which a plasma current flows.*

Several variations of these basic magnetic confinement machines have been built, often with the object of stabilizing the plasma for longer periods. Some attempt to reverse the direction of the magnetic field in a "reverse field pinch"; others, called "Stellerators", use extra coils to produce the poloidal field and thus increase the confinement time. With all of these devices it is not clear which, if any, will be the prototype of a final design.

In **inertial confinement** the objective is to compress and heat a pellet of the fusion fuel to very high densities by a focussed implosion. The hope is that the density will be high enough that even for the short confinement time determined by the resistance to motion or inertia of the fuel itself, the Lawson Criterion will be met. Various kinds of high energy beams, including lasers and particle beams, are being investigated to produce the implosion.

In laser inertial confinement, many intense laser beams are directed simultaneously onto a small spherical fuel pellet from all sides. The resulting blast of light energy vaporizes the fuel pellet container which may be made of glass or plastic. The resulting shock wave compresses the fuel to a very high density.

To this end, very large laser systems filling whole buildings have been built. Examples are the Nova and Shiva lasers at the Lawrence Livermore Laboratories of the University of California.

An **operating fusion reactor** has not yet been achieved, but we can, with some certainty, describe many of the features it will have when it becomes a reality.

It will probably be part of a heat engine, that is, its primary purpose will be to produce heat, which may be extracted from the machine to make steam to drive turbo-electric generators. Alternatively, the high temperature heat may be used directly; for example, in order to effect some desirable but energy-consuming chemical reaction. The fusion reactor will also be a plentiful source of neutrons. One possible use of the fusion reactor as a neutron source is to breed fuel for fission reactors out of otherwise non-fissionable material such as thorium.

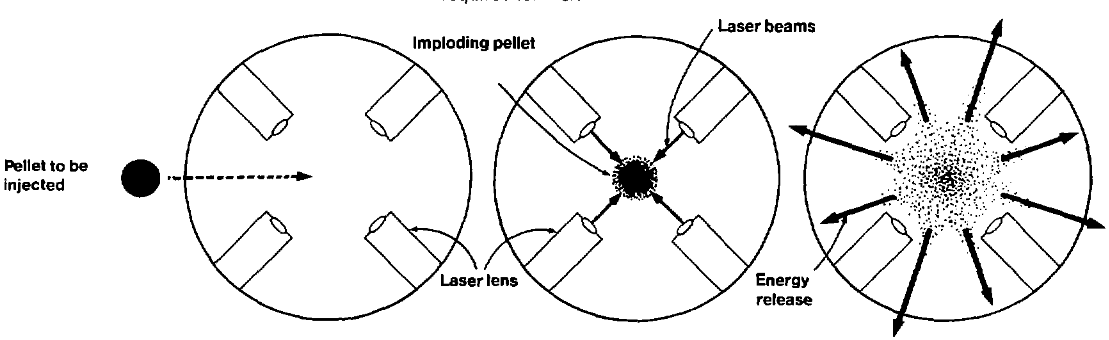
The fuel of the first generation machine will be a mixture of deuterium and tritium. The deuterium will be extracted from heavy water, a technology in which Canada is a world leader; this fuel is virtually infinite in its supply. The tritium is another matter; it is probable that the machine will manufacture its own. In reaction number one in Table 1, 80% of the energy is removed via the neutrons. This energy, of course, must be captured. But neutrons, having no charge, pass out of the magnetic confinement and indeed it will be difficult to keep them in the machine at all. However, if the machine were surrounded with a thick "blanket" of the light metal lithium, the neutrons would react with the lithium nuclei to produce tritium by the reaction

$$Li + n \rightarrow He + T$$

and in the process, transfer their energy to a heat exchange medium. The lithium may be in the liquid state and be continuously pumped in and out of the blanket to remove both the heat and the tritium. Thus the reactor will manufacture, or breed, one of its own fuels: tritium from lithium.

It follows that the energy resource of these first-generation fusion reactors will not be essentially infinite. It will be limited by our resources of the metal lithium which are comparable to our resources of uranium in energy potential.

(Fig. 10) *In inertial confinement schemes, tiny glass beads containing a D-T fuel mixture are imploded by laser beams, creating the super-high temperatures and densities required for fusion.*

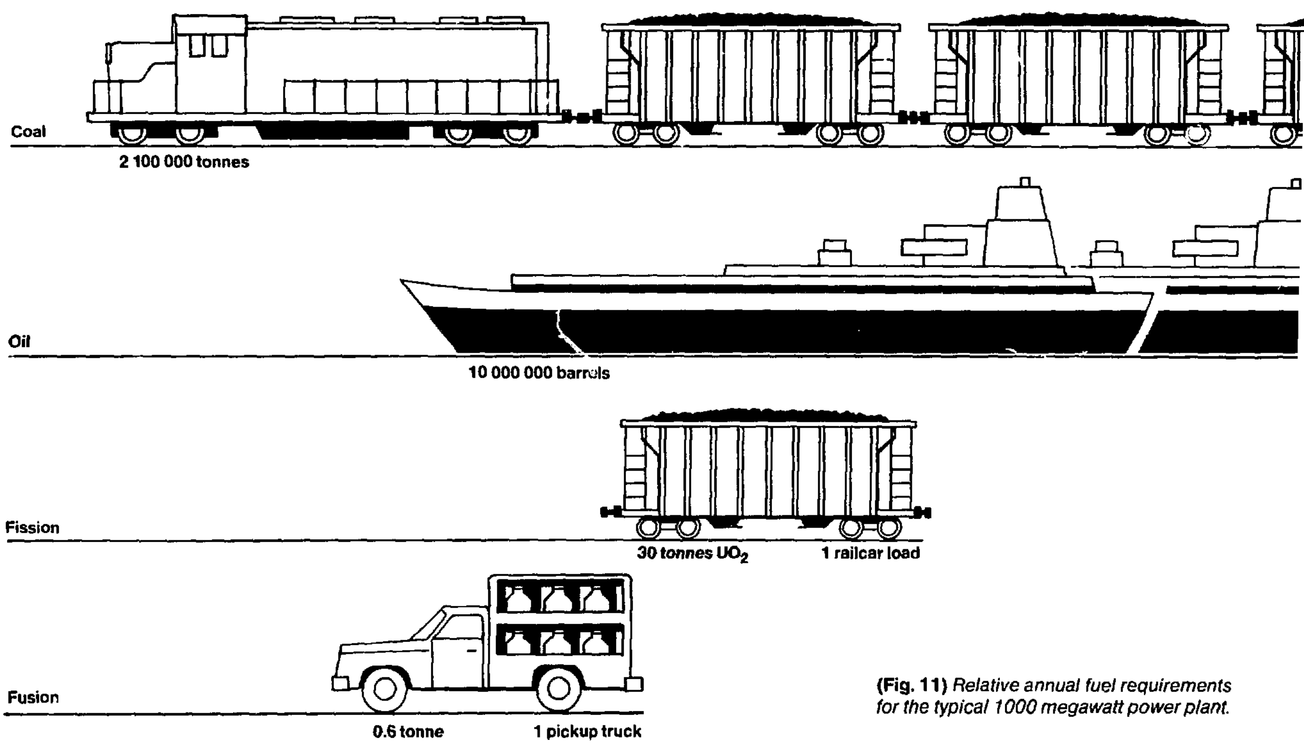


THE IMPACT OF FUSION POWER

It is clear that the first generation of fusion reactors will not be able to claim an inexhaustible source of fuel since they will require the use of lithium. Nevertheless, the earth's supply of this metal is very large and the fusion energy resource is as large or larger than any that we now have. More importantly, success in the first round will provide the incentive, and be the proving ground for the development of true deuterium fusion in the future. This achievement will indeed provide the era of inexhaustible energy for our descendants. Even the first-generation fusion reactors will have many attractive aspects when compared to today's energy systems.

A major portion of the world's transportation systems is devoted to the transport of fossil fuels. A single one thousand megawatt (MW) electrical plant requires twenty thousand railcars of coal per year. This amount of transport constitutes a large drain on our energy resources, not only in direct fuel, but also in the system itself, since it is built with energy intensive materials like steel. The system requires a large energy investment. An oil-fired plant involves similar volumes of fuel and transportation. In contrast a one thousand MW uranium fission plant requires the equivalent of one railcar load of uranium dioxide per year, and the fuel for a fusion plant (½ tonne) can be carried in a pickup truck!

The detrimental impact on the environment is another problem that will be greatly reduced. A one thousand MW coal-fired plant produces two thousand railcars of ash and clinker per year which must be transported to landfill sites; the leaching of chemicals from these sites is a concern. About one hundred and forty tonnes of sulphur oxides per day go up the stack of such a plant and are a source of acid rain. An equal amount of nitrogen oxides is dispersed in the atmosphere. Oil has little ash, but is hardly better in terms of atmospheric pollution. There are no comparable emissions from either fission or fusion plants.



(Fig. 11) *Relative annual fuel requirements for the typical 1000 megawatt power plant.*

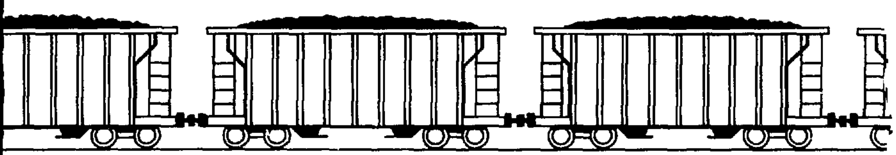
For fossil fuels, the process of combustion is one of combining carbon with atmospheric oxygen to produce carbon dioxide which is released into the atmosphere. This form of pollution is the least well understood and perhaps the most dangerous pollution of all in its potential to alter the world's climate. Fission and fusion produce no such problems.

Radioactivity, radiation and their possible threat to human health, loom large in the public mind and are much misunderstood. It is not generally appreciated that coal-fired plants are producers of radioactive atmospheric contaminants. These arise from uranium and thorium impurities in the coal which enter the atmosphere as particulates which are easily retained in the lungs. Fusion reactor systems will, of course, contain rather large quantities of the radioactive gas tritium. The reactor will also produce various tritiated wastes which must be reprocessed in order to recycle the valuable tritium fuel. The technology for handling tritium and its wastes is very well developed, especially in Canada. In the case of a release, tritium enters readily into biological systems in the form of isotopic water HTO, but its retention time in the human body is relatively short.

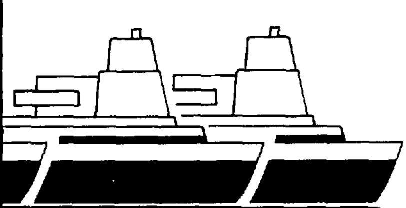
The structural parts of the reactor will, like the fission reactor, become radioactive as a result of neutron bombardment. Such radioactivity, however, is relatively short-lived compared to that of fission fragments in uranium reactors. The safe storage period for discarded parts will be measured in decades for fusion reactors, rather than centuries, as for used fuel rods from fission reactors.

Features to prevent plant accidents account for a great deal of the complexity of fission reactors. These features are necessary because the fission fuel contains an enormous amount of stored energy in the form of radioactive fission fragments which continually generate heat. In the event of an accident, the cooling of the fuel must be maintained. Fusion fuel contains very little stored energy at any time.

Since no working reactor has yet been built, it is difficult to assess the economics of fusion energy. Several studies of projected plants indicate a capital cost about twice what would be competitive today. However, the price increase of conventional fuels and further technological development may well make fusion competitive in the next century.



191 trains, 110 cars each



10 supertankers

INTERNATIONAL FUSION RESEARCH

Fusion energy research is an expensive enterprise but if it is successful, its benefit to mankind will be immense. For these, and many other reasons, there has been a high degree of co-operation between nations on fusion energy research and development. The four major participants in the international fusion research scene are: the U.S.A., the European community, Japan and the U.S.S.R. Each of these has a well-developed research program in Tokamak plasma confinement and each has built, or is building, a large Tokamak designed to achieve "energy breakeven" conditions.

The U.S.A. has a very large research program involving many kinds of toroidal machines. The "Tokamak Fusion Test Reactor" (TFTR) at Princeton University is expected to achieve energy breakeven before 1990. The U.S.A. also has the world's most extensive programs on mirror machines and laser inertial confinement.

Several European countries have built various magnetic confinement facilities. In 1978, nine European countries joined in a consortium to build the "Joint European Torus" (JET) in England; it became operational in 1984.

Japan was a latecomer to fusion research but has advanced rapidly, to the stage that its large Tokamak "JT-60" will be completed in 1985. Japan also conducts research on mirror machines and laser inertial confinement.

The U.S.S.R. is the country which invented the Tokamak concept, and their large machine, "T-15", is under construction. Russia also has a major program involving mirror machines.

TABLE 2: *The world's major fusion projects*

COUNTRY	TYPE	NAME	LOCATION
United States	Tokamak	TFTR PLT Alcator	Princeton Princeton MIT
	Magnetic Mirror	MFTF	Lawrence Livermore Laboratories
	Inertial Confinement	Shiva, Nova	Lawrence Livermore Laboratories
European Communities	Tokamak	JET	Near Oxford
Japan	Tokamak	JT60	Near Tokyo
U.S.S.R.	Tokamak	T15	Near Moscow
	Magnetic Mirror	Several	Near Moscow
Canada	Tokamak		Varennes

CANADA'S ROL[E] IN FUSION RES[EARCH]

The international budget for fusion research is about two billion dollars per year, spent largely by the four major participants: the U.S.S.R., the U.S.A., the European community and Japan. In the light of this enormous expenditure, it is difficult for a smaller but equally technologically advanced nation like Canada to participate in a meaningful way. Faced with the necessity to consolidate its investment in the CANDU fission reactor program, Canada has no[t] had the resources to be an early and large contributor to the fusion scene. The CANDU program, however, has given Canada a unique technological expertise which can be applied to fusio[n] energy research.

Since 1980, the state of fusion research in Canada has changed markedly, and three projects have been identified which give Canada a real presence in the international fusion scene and which utilize uniquely Canadian expertise and knowledge. The overall Canadian program is co-ordinated by the National Research Council of Canada.

A major Tokamak is being built at Varennes, near Montreal, by IREQ (the research branch of Hydro-Québec), the National Research Council of Canada (NRCC), the Universities of Montreal an[d] Quebec (I.R.N.S.), MPB Technologies Inc, and Canatom Inc. This is a mediu[m] sized machine, designed and built in Canada to investigate specific aspects o[f] Tokamak operation. The commissionin[g] and construction will be completed in 1985 at a cost of approximately forty million dollars. It will be operated by a staff of a hundred of which about forty will be scientists and engineers.

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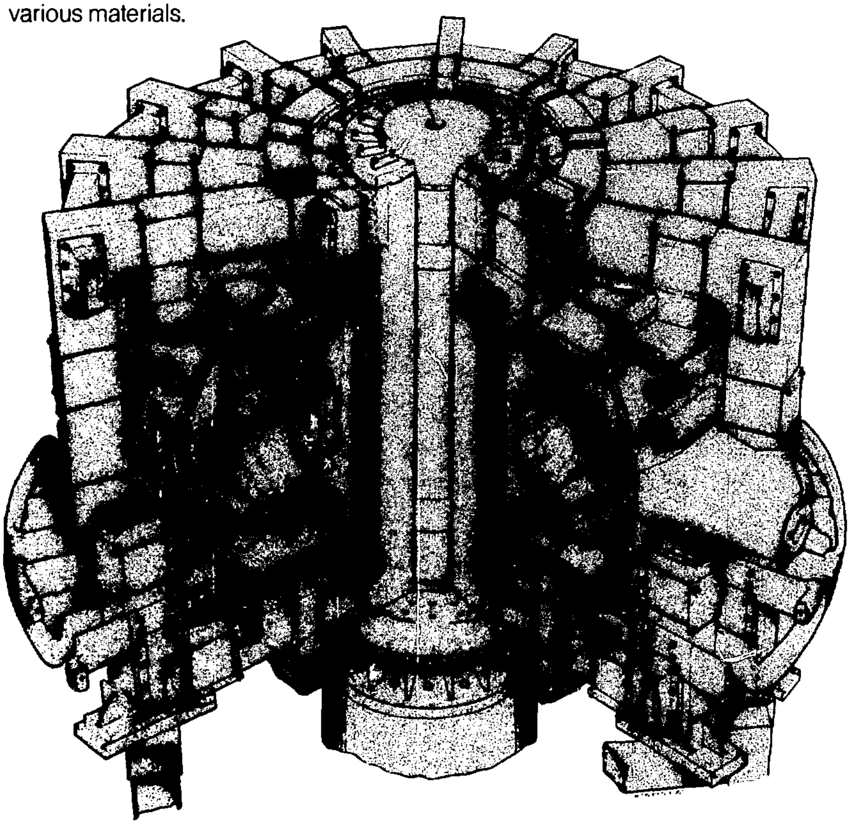
One of the major unresolved problems in Tokamak operation is how to run them continuously or with such long plasma pulses that their efficiency will be much improved. Tokamaks generally have pulse durations of the order of one second, but the Varennes instrument has been designed to investigate the operation of pulses up to thirty seconds in length, a duration not yet achieved elsewhere.

In addition, the Canadian machine will be used to study the interaction of the plasma with the inner wall of the toroid and with other materials inside the chamber. A major effort will also be made to develop diagnostic tools for studying the properties of the plasma and its interaction with various materials.

Another Canadian activity involves inertial confinement research. This is an appropriate area because of Canada's good international reputation in high-power pulsed laser research and development. Problems associated with the interaction of laser beams and solid targets will be investigated. This work is largely centered at the laboratories of the NRCC and of the Universities of Alberta and British Columbia.

A third important venture in fusion research has been taken in the CANADIAN FUSION FUELS TECHNOLOGY PROJECT (CFFTP), and INRS Energie (Québec).



(Fig. 12) *A schematic view of the Tokamak de Varennes.*

The emphasis on fusion fuels arises from several remarkable aspects of Canadian science and technology. In the realm of fundamental science, Canada has a long standing reputation in the study of the properties of hydrogen. This research started after World War I with the pioneering work of Prof. John McLennan at the University of Toronto, and today is carried on intensively in several universities and laboratories.

One of the fuels used in fusion reactors will be deuterium, which is derived from heavy water. Experience in the CANDU nuclear program has made Canada the world leader in the technology and production of heavy water.

The other fuel used in fusion will be the radioactive gas tritium. It happens that Canada is also a major producer of tritium. This isotope of hydrogen is produced in the CANDU nuclear reactors by the bombardment of the deuterium in heavy water by neutrons. Tritium is radioactive and its concentration builds up with time in the moderator and coolant systems of CANDU reactors and contributes to the radiation dose of CANDU station workers.

Technologies have been developed to remove tritium from these reactor systems, but what is a nuisance to CANDU station operators is also a fusion fuel, and offers a possibility for commercial development. CANDU's will never produce enough tritium to fuel commercial fusion reactors; these reactors will manufacture their own. However tritium will be required in substantial amounts for advanced fusion experimental reactors and for the startup of commercial fusion reactors when they are built.

THE CANADIAN FUSION FUELS TECHNOLOGY PROJECT

The Canadian Fusion Fuels Technology Project (CFFTP) has been launched to strengthen Canada's scientific and industrial base in regard to fusion fuels technology and to co-ordinate the application of that technology to international fusion power development programs. The project is a national program backed by funding from the federal government, the Ontario provincial government, and Canada's largest electrical utility, Ontario Hydro.

The CFFTP project was formally launched in 1982. From the outset, CFFTP has operated a program of contracted-out research and development. The R&D program is directed towards the further development of existing Canadian capabilities in five of the six major fusion technologies. These include Tritium Technology, Breeder Technology, Materials Technology, Equipment Development (remote operations) and Safety and Environment. Magnet Technology is not addressed by the project. The R&D management activities are organized within CFFTP under a Technology Development function. The theme of tritium constantly runs through all five areas with remote operations as the main emphasis in the equipment development area.

The program is based on the extensive technology developed for the handling of tritium in the CANDU system. It is estimated that of the twenty billion dollars of the capital value of the CANDU system in Ontario, about two billion worth of research, development and acquisition activity has been expended by Ontario Hydro and Atomic Energy of Canada Limited to manage tritium. It is this strong foundation and present capability that make the Fusion Fuels program immediately viable and relevant to fusion programs in the U.S.A., Japan, and Europe.

There has been an immediate opportunity for Canadian industry to provide specialized engineering services and consultation. Within the CFFTP organization, these specialized activities have been arranged through a Technology Applications function. Funding for these activities is provided on a contract basis by the organization requiring the service.

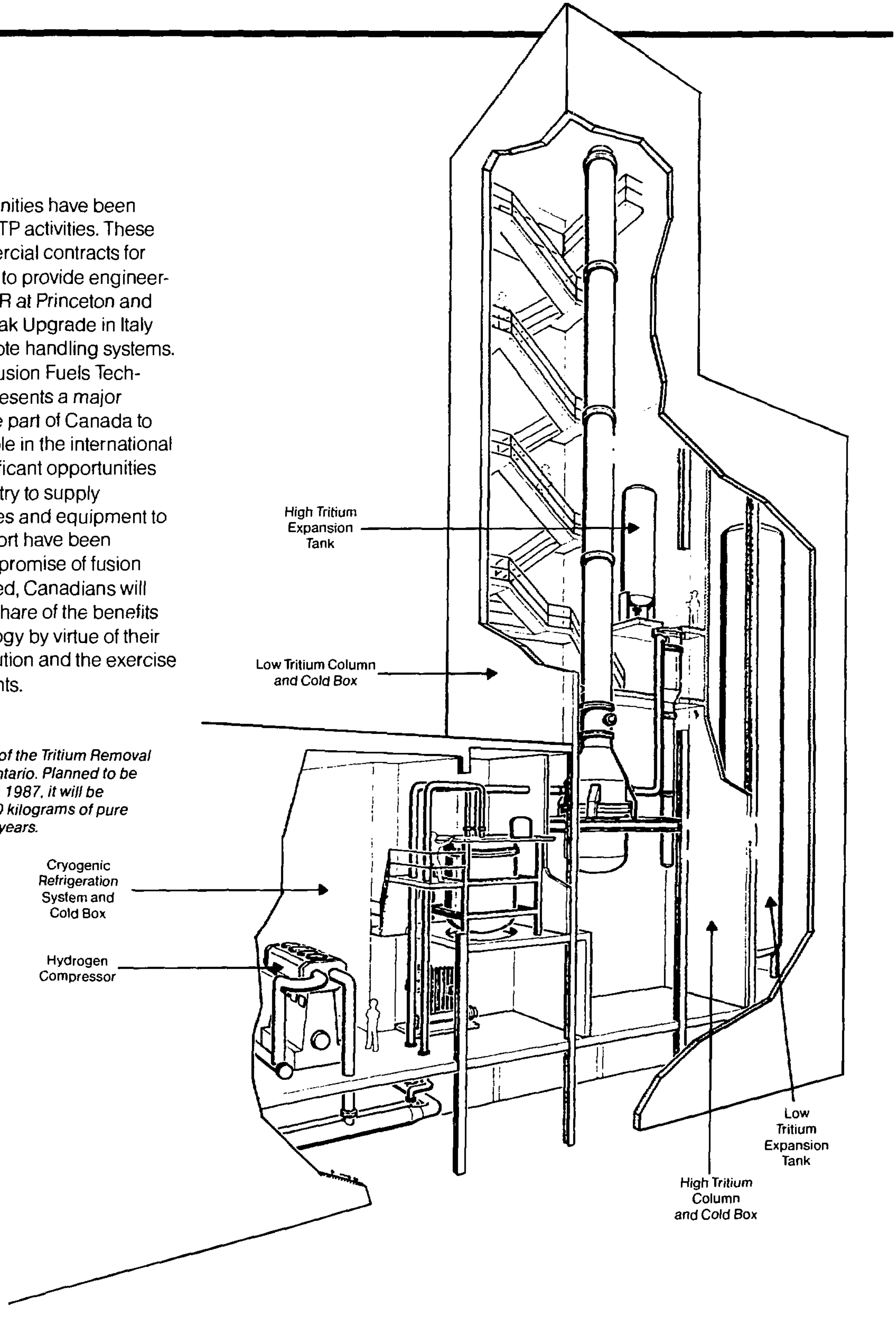
During the first two years of the project, CFFTP managed $3.9 million of project funds through seventy-two contracts with subcontractors. Supplementary funding of approximately $1 million was provided by subcontractors, for a total expenditure of $4.9 million. More than one hundred and fifty people from twenty-two organizations and consulting companies in Canada participated in technical work related to this fusion fuels project.

For 1984-5 it is estimated that the $4 million dollar budget will be allocated with approximately 15% going to program management and operation, 17% to industry and consultants, 13% to universities, 25% to Ontario Hydro and 30% to AECL. It is expected that supplementary funding by subcontractors will be offered up to $1.7 million for a total 1984-5 expenditure of $5.7 million.

Recognition of the CFFTP program and the value of existing Canadian tritium and remote operations technology has been apparent through the broad requests for project reports, the quarterly Newsletter, and requests for the attachment of personnel to the Joint European Torus (JET) in England, the Next European Torus (NET) design team in Germany, the Fusion Engineering Design Centre at Oakridge (FEDC), the Tokamak Fusion Test Reactor (TFTR) at Princeton, UCLA, and the University of Rochester, EG&G at Idaho Falls and the Tritium Systems Test Assembly (TSTA) at Los Alamos. These assignments have the goal of providing assistance in program planning, performing conceptual and detailed studies, and in some cases, providing assistance in the commissioning of tritium and remote operations systems.

Spin-off opportunities have been developed by CFFTP activities. These have led to commercial contracts for Canadian industry to provide engineering services to TFTR at Princeton and the Frascati Tokamak Upgrade in Italy on tritium and remote handling systems.

The Canadian Fusion Fuels Technology Project represents a major commitment on the part of Canada to play a significant role in the international fusion scene. Significant opportunities for Canadian industry to supply engineering services and equipment to the international effort have been realized. When the promise of fusion energy is established, Canadians will be able to claim a share of the benefits of this new technology by virtue of their substantial contribution and the exercise of their unique talents.



(Fig. 13) *Cutaway view of the Tritium Removal Facility at Darlington, Ontario. Planned to be fully operational early in 1987, it will be capable of extracting 50 kilograms of pure tritium over the next 20 years.*

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