Click here for Full Issue of EIR Volume 13, Number 38, September 26, 1986

Fusion reactor technology for the 21st century

Part II of Dr. V. K. Rohatgi's review of scientific progress toward the limitless energy source of the future.

Dr. Rohatgi is head of the Plasma Physics Division at the Bhabha Atomic Research Center in Bombay, India. He also directs India's MHD (magnetohydrodynamics) program. This review of fusion technology was written in 1985. Part I discussed the present status of the international fusion effort, starting with the magnetic confinement approach, best known in the form of the tokamak. Here we continue with Dr. Rohatgi's discussion of the second principal approach, inertial confinement fusion, and begin to consider the technology requirements for building a fusion reactor. Readers wishing to consult Dr. Rohatgi's extensive bibliography may obtain a copy from EIR.

From the operating experience with drivers available today, it is possible to attempt a design of an inertial fusion reactor. Here are the major considerations for the design of inertial fusion (Monsler et al. 1981):

- Fusion energy gain (product of driver energy E and pellet gain Y) governs the overall plant efficiency.
- The power of a plant is related to the product of energy of a driver pellet gain, and the repetition rate of the reaction.
- Driver energy, in turn, is the product of the energy input and the efficiency of the driver. Consequently, the efficiency of a driver is an important figure in the design of a power reactor.
- Thermal and dynamical stresses, temperature limits, and the recovery time of the reactor cavity influence the choice of fusion energy gain per pulse and the repetition rate.
- Reliability and long-time fatigue are the additional constraints in the selection of these parameters.

Because of low driver efficiencies and pellet gain, present-day designs prefer a fusion-fission hybrid structure, instead of a pure fusion reactor. The tentative inertial confinement fusion-fission reactor designs are listed in **Table 6.** These examples use laser, relativistic electrons, and heavy ion beams as the drivers for the thermonuclear reaction. Other important parameters such as the pellet gain, tritium breeding ratio, beam energies, repetition rate, and so on, are shown in the table. It is interesting to note that these parameters cover a wide range of operating conditions. A typical energy flow diagram in the case of laser-induced fusion reactor (the revised Hylife design) is shown in **Figure 7**. The design assumes a laser of 3% efficiency, which is incident on a pellet gain of 900. Further energy multiplication by a factor of 1.18 takes place at the blanket. The overall efficiency (taking into account recirculating power) is estimated to be 33%.

The overall objective of the inertial fusion program of the U.S. Department of Energy is summarized in **Table 7.** This table outlines the development of facilities, applications, and technical issues to achieve the objectives and tentative acceptable gains from the pellet for different applications. The proposed interrelationships between inertial confinement fusion technology development activities and major demonstration facilities are shown in **Figure 8.** This figure indicates the steps necessary between the early single-pulse target facility and the prototype fusion power plants of the future. The major tasks are divided into the following stages:

SPTF (Single Pulse Target Facility): The objective will be to demonstrate acceptably high fusion gain.

SIA (Systems Integration Activity): The objectives will include integration of testing pellet, injection, tracking, targeting systems, and repetitive operation.

PFA (Pellet Fabrication Activity): This will include the process development and testing of large quantities of pellets with acceptable tolerance and cost.

ETF (Engineering Test Facility): This facility will be used to test reactor cavity concepts, blanket concepts, reactor

TABLE 6

Typical inertial confined fusion—fission reactor designs

Parameters	**Sandia Lab**	**Westinghouse**	**Lawrence Livermore Nation Lab (Hylife)**	**University of Wisconsin (Solace)**
Nature of driver	Relativistic electron/ light ion beam	Heavy ion beam	Laser	Laser
D-T pellet gain	18	175	400	150
Tritium breeding ratio	> 1.4	> 1.2	1.7	1.3
Beam energy (MJ)	4	2	4.5	1
Pulse rate (Hz)	10	10	1.5	20
Electrical power output (MW)	1,075	1,346	1,004	965
Net system efficiency (%)	31	31.3	32	29

driver interphase, and pulse inertial confinement fusion radiation effects.

MTF (Materials Test Facility): This will be dedicated to study the long-term materials behavior under various operating conditions, such as high-rate pulse radiation, effects of chemical, mechanical, and thermal environments, and high cycle fatigue.

EPR (Experimental Power Reactor): This is required to demonstrate the overall engineering feasibility of inertial confinement fusion, confirm prototype plant technology, produce significant thermal power (100 to 300 MW), and generate data for extrapolation to the next stage.

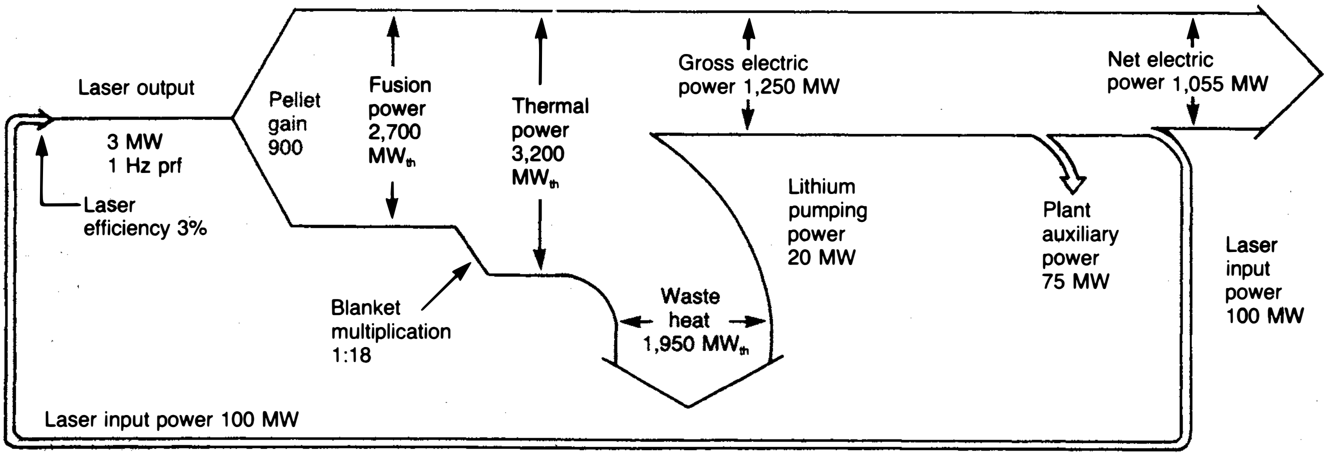
PFPP (Prototype Fusion Power Plant): This is expected to be the final facility in the inertial confinement fusion development program. The plant should be capable of operation as a commercial unity, yielding necessary data on cost, reliability, and other industrial acceptance aspects.

In terms of priorities, the first four items are considered as early facilities and activities, and the last three are the second phase of the total development program. It is envis-

FIGURE 7

The average power flow for the Hylife power plant

Inertial confinement fusion reactor concepts



Gross electrical efficiency = 39.0%   New electrical efficiency = 33.0%   Recirculating power fraction = 15.6%

TABLE 7

Potential inertial confinement fusion applications

U.S. Department of Energy inertial fusion program

Facility	Application	Technical issues	Gain
Single pulse test facility	Weapons physics	Ignition and propagating burn	10^{-2}-10
	Validity of driver-target requirements for higher gain	Low-cost driver technology	
Fuel production facility	Material production	Low to moderate gain scaling	10-50
	Validation of • Driver-target requirements for commercial power production • Automated target fabrication • Reactor concepts	Repetitively pulsed driver technology Reactor engineering Target fabrication and automation	
Commercial prototype	Demonstrate inertial fusion as a competitive power production source	Plant engineering Multiple reactors	100-300

aged that the entire program will spread over several decades and may need modifications on the basis of experience gained during the earlier stages.

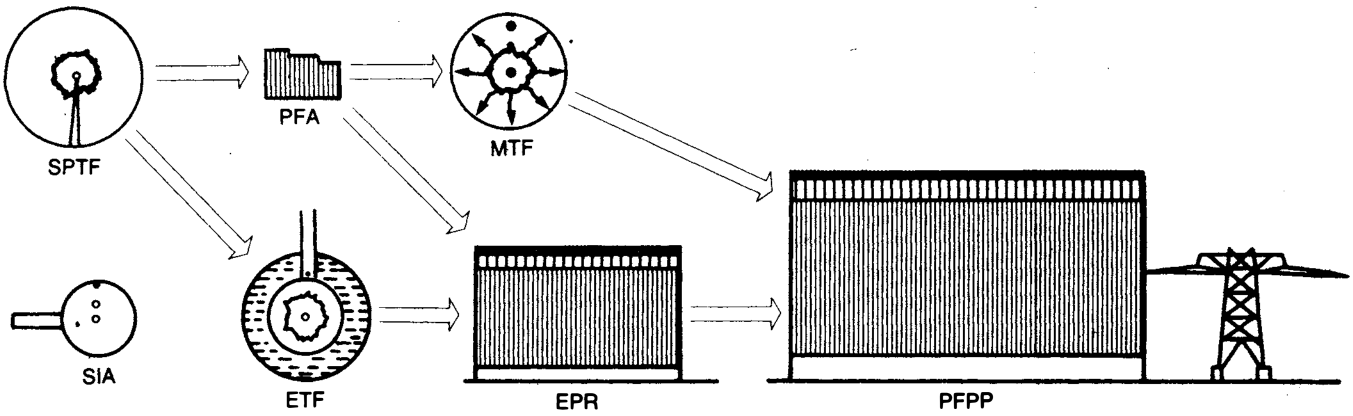
Technology requirements

Having taken a look at the present activities, concerning the developments of fusion power reactors, it is now possible to list the technological requirements for building a fusion reactor. Here are the major issues identified for this purpose:

Understanding of plasma physics: Although there has been significant progress in understanding the basic physics, several new questions have opened up. The first-order physics necessary for the conceptual design of fusion reactors has been well established. Now it is necessary to gain better understanding of the details of the physical phenomena active in a reactor. These issues include the topics of basic plasma

FIGURE 8

Inertial confinement fusion technology development activities and major test/demonstration facilities



SPTF: Single pulse target facility

SIA: Systems integration activity (objectives: to perform integrated testing of pellets, injection, tracking, targeting system, and repetitive operation)

PFA: Pellet fabrication activity

ETF: Engineering test facility (objectives: to test reactor cavity concepts, blanket concepts, reactor driver interface, and pulse inertial confinement fusion radiation effects)

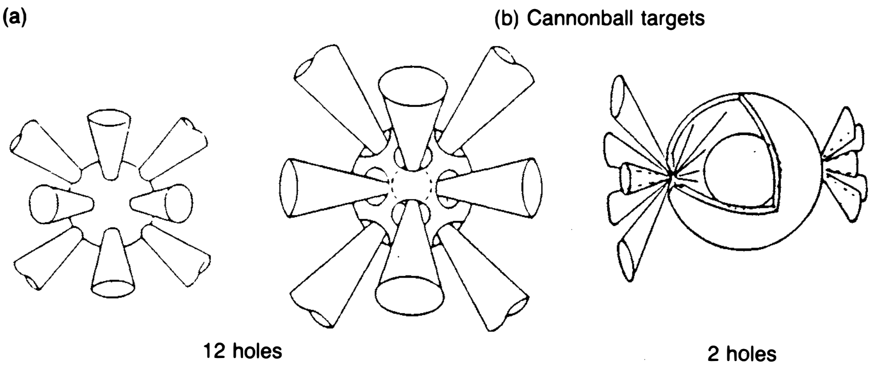
MTF: Materials test facility

EPR: Experimental power reactor

PFPP: Prototype fusion power plant

FIGURE 9

Laser fusion target configurations



Direct

physics as well as topics of an engineering nature. For instance, there is scope for research in the areas of generation of fusion-grade plasma, thermal transport in tokamak (Furth 1985a) and its optimum shape for stability. Plasma heating mechanisms and the scaling laws for plasma flow are other topics of interest for investigation. The physics involved in the beam-target interaction is fairly complex. The target design dealing with fusion physics and transport of energy are important areas for investigations. Better understanding of the physics of these phenomena can lead to simplifications in the reactor designs. Many laboratories in the world are engaged in the studies of these and other related subjects. These investigations are vital, since this knowledge will help in better definition of the requirements for fusion reactor. See for instance, the analysis of the plasma of a tokamak fusion engineering device carried out by Peng et al. (1982).

Fuels: The first choice of fuel for fusion energy is the deuterium-tritium (DT) mixture, because of its higher energy yield at relatively low ignition temperatures. In this case, preparation and handling of tritium and large fluxes of fast neutrons pose technological difficulties. Also, with the presence of large inventories of radioactive materials, the maintenance of equipment and safety demand special considerations. It is in this context that one should study other reactions such as the following:

$$P + {}^{11}B \rightarrow 3{}^{4}He + 8.7\ MeV$$
$$P + {}^{6}Li \rightarrow {}^{3}He + {}^{4}He + 4.0\ MeV$$

These reactions take place between protons and boron and between protons and lithium, which occur in nature. Also, the reaction products in these cases are free from radioactivity. Of course these reactions take place at much higher temperatures and yield relatively less energy when compared to the DT fuels. Reaction in DD systems has also been studied for fusion applications.

Notable programs for preparation, remote handling, and inventory management of tritium exist in Japan, as well as other places. The research programs at the universities in Japan emphasized measurement of tritium penetration rates through various materials, study of tritium containment material, and tritium waste treatment and storage.

Design, fabrication, and injection of fuels in reactors is also an important issue. In the magnetic confinement fusion reactor (MCFR) experiment, the characteristics of the plasma are affected by the mode of injection of fuels. For example, the Lawson criterion in MIT's Alcator was significantly improved when fueled with solid pellets instead of gas puffs (Greenwald et al. 1984; Schwarzschild 1984). Similarly, the design, fabrication, and testing of fuel pellets, injection system and synchronization of target with driver beam-firing have been identified as major tasks by the U.S. Department of Energy (SIA in **Figure 8**).

The design and fabrication of directly and indirectly heated fuel targets for inertial confinement fusion reactors is one of the major issues for investigation. Configurations of conceptual targets are shown in **Figure 9**. In the direct-drive target, the laser beams are symmetrically incident on the front surface of the target. Two different geometries of cannonball (indirect drive) are also shown in the same figure, with 12 and 2 holes. The incident beam energy entering through these holes is first converted in the form of x-rays, which compress and heat the fuel pellet (Stevens 1985). Physics of indirect-drive targets is discussed by Winterberg (1980), Yabe (1984), Yabe and Mochizuki (1983), and Yamanaka (1984). Another interesting development in recent years has been the realization that by using polarized spin fuels, the reaction rates (Takahashi and Lazareth 1983) in DT and DD can be increased by 1.5 and 2.5 times respectively. Similarly, reaction rates can be enhanced by using catalyzed DT fuel (Jones 1984). Consequently, higher-energy yields are possible at lower temperatures. In-depth study of this possibility especially with reference to power reactor design will be very valuable (Kulsrud 1984; Kulsrud et al. 1982).