power plant was in operation in the United States, bringing nuclear fusion to economic fruition may well take an even longer period of time. The fusion technology is much more complex, and, as I will demonstrate, we have yet to show that the fusion reaction can be sustained; i.e., we have yet to reach the point with nuclear fusion that we reached with nuclear fission on Dec. 2, 1942. Of course, our scientists involved in fusion research are quite optimistic about their program because of recent developments in the field, and they may prove that I was too conservative in my prediction of the time required to develop a commercial-scale fusion reactor. The reason for some of their enthusiasm will be evident in a moment.

What is involved in the attainment of controlled fusion? What progress are we making? What will be the ultimate payoff?

Efforts to control the release of thermonuclear energy have been going on in the United States and abroad for somewhat less than 20 years. We know that there are several possible fusion reactions using the nuclei of light elements which can be the basis for controlled fusion. Two are deuterium–deuterium (D–D) reactions. The third is a deuterium–tritium (D–T) reaction, and the last is a deuterium–helium-3 (D–^{3}He) reaction:

Equal probabilities

$$\begin{cases} {}^2_1D + {}^2_1D \longrightarrow {}^3_2He + {}^1_0n + 3.2\ MeV \\ {}^2_1D + {}^2_1D \longrightarrow {}^3_1T + {}^1_1H + 4.0\ MeV \end{cases}$$

$$ {}^2_1D + {}^3_1T \longrightarrow {}^4_2He + {}^1_0n + 17.6\ MeV$$

$$ {}^2_1D + {}^3_2He \longrightarrow {}^4_2He + {}^1_1H + 18.3\ MeV$$

Basically three things must be accomplished to demonstrate that the fusion reaction can be sustained: (1) The deuterium fuel must be heated to between 100 million to 5 billion degrees Kelvin, corresponding to 10,000 to 500,000 electron volts (depending on the fuel cycle). (2) The resulting ions, the plasma, must be held in a configuration where their density is of the order of 10^{15} ions per cubic centimeter. (3) The confinement time of the hot ions at these densities must be of the order of tenths of a second if the ions are to undergo fusion. It is important to note that, if the densities are higher, the confinement times can be correspondingly shorter. Alternatively, if they are lower than 10^{15} ions per cubic centimeter, then the confinement times must be longer.