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Fusion: The Energy Promise. Co-produced by Nova and BBC TV. Distributed by Time-Life Multimedia, 100 Eisenhower Dr., Paramus, NJ 07652. 16 mm, color, 52 min. Price: $550 purchase, $60 rental. Released 1974. *Topic:* Traces the history of the international race to achieve fusion with an explanation of the scientific principles involved. *Level:* College and general adult. (Reviewed by Richard K. Osborn.)

Fusion: The Energy Promise is a very good film for its intended purpose; namely to sketch some of the history of controlled thermonuclear research (CTR) undertaken by several countries—mainly Britain, the United States, and Russia—circa 1950 to 1974. Since this research grew out of weapons programs, it was naturally classified. Also, since it began before many of us foresaw the coming energy crunch, it did indeed start off as a race with national technological prestige in the balance.

Among the insiders there was considerable optimism that simple physical principles prevailed and that the construction of a successful fusion energy machine involved only engineering details—complex details, to be sure, for the problem of containing a gas of electrons and ions at temperatures of the order of several hundreds of millions of degrees was recognized to be a formidable one. But the very fact that the gas consisted of charged particles suggested the solution; i.e., construct magnetic bottles. So bottles were built—open-ended bottles called mirror machines, closed-ended bottles called toroidal machines, and some variants upon both themes.

Then, at the 1958 Geneva Conference on the Peaceful Uses of Atomic Energy, CTR was declassified. Full-scale and small-scale models of various devices and bottles were placed in exhibit. Ideas and theories were exchanged, and finally some of the concepts of nuclear fusion achieved a little public visibility. Shortly thereafter some of the machines were fueled with deuterium and the results were exhilarating—neutrons, the signature of the D–D fusion reaction, were detected emerging from the machines. But the exhilaration was short-lived. It was soon discovered that the fusion reactions producing the observed neutrons were not thermonuclear in origin, i.e., not originating from reactions between fairly equilibrated deuterons in the hot plasma, but rather due to D–D reactions among deuterons executing ordered motion or even between deuterons leaving the plasma and hitting other deuterons previously plated out on surfaces. The rate of such reactions would never scale to the level of net energy gain. Optimism gave way to pessimism and CTR stagnated—and even declined.

The end of the Fifties and the beginning of the Sixties saw the dawn of a new era as the realization sank in that all those machines were really only tools for experimental research in plasma physics. The emphasis in CTR turned from the building of reactors to the theoretical and experimental study of the plasma state of matter. The effort paid off, for there rapidly developed an appreciation of just how little this most prevalent (other than terrestrially) state of matter was understood.

Then in the mid-Sixties some new ideas emerged that began to rekindle a cautious new optimism for CTR. One was the development by the Russians of their Tokamak, a conceptually simple combination of the old toroidal bottle with some of the principles of the old betatron accelerator. The startling thing about the Tokamak was that its performance was claimed to be a quantum leap beyond that of any device previously constructed. These claims were skeptically received, so a team of British scientists were invited to Moscow to see for themselves. They went, they saw, and the skepticism dissolved. Almost immediately, programs for the construction of Tokamaks were undertaken in laboratories all over the world—four in the United States: at the Oak Ridge National Laboratory, at the University of Texas, at the Plasma Physics Laboratory in Princeton, and at the Massachusetts Institute of Technology. Tokamak research has been escalating ever since, hopefully toward the ultimate realization of a real fusion reactor.

A second idea that began to take root in the mid-Sixties was that of laser fusion. The notion here was to bring a small pellet of fusion fuel to ignition temperature and promote burning, before time for disassembly, by means of a high-power, pulsed laser. This came to be called inertial confinement. At that time this idea, to most, seemed laughable, for it was easy to show that the demands on laser technology to achieve net energy gain by this method were many orders of magnitude beyond the state of the art. But here again, people working in the classified area of weapons technology weren't laughing. Circa 1972 the notion that matter might be compressed by factors of thousands to tens of thousands with laser beams was declassified, and then it became apparent that the demands on lasers for laser fusion might not be so far from the state of the art after all. Almost explosively (no pun intended), research on this new prospect for fusion was initiated in many laboratories in many countries, with huge programs at the Lawrence Livermore Laboratory in California and the Los Alamos Scientific Laboratory in New Mexico.

The decade of the Seventies is characterized by an important new development in fusion research. What began as a competition, or race, between nations in the early Fifties is evolving into multinational collaboration. The enormity of the problems remaining to be solved before fusion machines can be realized is now better understood, and the pressure to tap a large, new energy resource is beginning to be felt. Slowly but, I think, surely, competition is giving way to cooperation.

A second, and truly secondary, point to which this film is addressed is some explanation of the physical principles involved in the exploitation of nuclear fusion. In my opinion this matter is not dealt with very well. Only deuterium–

tritium fusion is discussed in the attempted explanation, but all references to our vast energy resources in water imply deuterium–deuterium fusion. This is somewhat misleading, but will probably go unnoted by the intended audience. The D–T fusion process, involving attractive nuclear forces and the competition with repulsive electrostatic forces which causes the ignition temperature to be so high, is described by a sort of real people animation provided by a school yard full of children. I would have preferred true animation which, if carefully worked out, could have provided a better, simpler, and clearer description in the same—if not less—time. But the thrust of this film is history, not physics, so I do not regard these defects as being too serious.

The narration (provided mainly by David Rose of MIT, who has himself participated in some of this history sketched by the film), organization of subject matter, and photographic quality are very good. It was a pleasure to meet on the screen some of the people who played important roles in this nearly thirty-year-old struggle to harness the energy that powers the stars. I believe that a substantial audience will find this presentation interesting and informative.

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