U.S.-USSR Presentation:

The Current State and Prospects for Development of Controlled Thermonuclear Fusion

Exclusive to NSIPS

Dec. 10 (NSIPS) — The following are excerpts from a joint presentation by E.P. Velikhov, Director of the Kurchatov Institute in Moscow and Edwin E. Kintner, Director Division of Magnetic Fusion Energy, U.S. Energy Research and Development Administration, Washington, D.C. before the Nov. 18 meeting of the American Nuclear Society and the European Nuclear Society. The presentation is the most important joint U.S.-USSR statement on the scientific feasibility of the mainline approaches to developing fusion power.

Introduction

Those of us working in fusion energy research and development are more confident than at any time in the past that practical fusion power can be achieved by the end of this century. The national plans of a number of countries are directed to this objective: first of all, the USSR plans presented in the XXV Communist Party Congress Directives on Socialist Economy Development for the Xth five-year period, and the USA national plans laid down in ERDA program plans. The plans of other European countries and Japan support this objective.

We are extremely encouraged by experiments in the last three years that suggest our present aggressive strategies are correct and have a good chance of success. In tokamak research, we have seen important progress in the confinement and magnetic thermoinsulation of plasma as well as plasma heating with injected neutral beams and radio-frequency waves. Questions of larger plasma size, higher magnetic fields, and higher currents have been answered so that we now know much more about the laws governing plasma transport and scaling to larger plasma sizes. As a result, higher plasma temperature, density, and longer confinement times are attainable and we are getting closer to reactor parameters. Thus, we have passed through the phase of concept demonstration, confirmation of main physical principles and establishing certain regularities, both theoretical and experimental, and now we are in the phase of attaining near reactor parameters and elaborating the basic engineering means needed for reactor construction. In the next phase, in an appropriate generation of devices which we will discuss in our report, we intend to study plasma with reactor parameters and develop scientific and engineering bases for thermonuclear power reactors. This first generation of actual reactors is in various stages of design in the Soviet Union, Japan, the Euratom countries, and the United States. Both the US and the USSR are considering the following step — the creation of prototype experimental power reactors. We will tell you about these plans later. Finally, we would like to discuss our ideas on power reactors and directions for their improvement over designs already put forward. There exist optimistic considerations that practical fusion power plants can well be much smaller and less costly than the earliest conceptual studies indicated.

At the same time that great progress is being made in tokamaks and other magnetic confinement concepts, investigations of using thermonuclear microexplosions (so-called "inertial confinement") have moved forward as well and now we are in the second stage of that development — the stage of confirmation of main physical principles for systems using lasers and electron relativistic beams to compress and heat microtargets, and also systems using magnetic fields for these purposes. The feasibility of more than a hundred-fold compression of thermonuclear fuel and its heating up to tens of millions of degrees has been demonstrated. Thermonuclear neutrons have been obtained in both the USA and the USSR by this method. Elaboration of the engineering necessary for reactor construction has begun. Devices of the next generation on which one can expect obtaining significant thermonuclear yield and establishing the main principles of the complex hydrodynamic and plasma processes of energy absorption, its transportation, acceleration of compressible shells, and compression and burning of fuel, are being designed and built. We would like to discuss briefly the potentials of this energy production method, called by Prof. E. Teller the "internal combustion engine of the XXIst century."

We must find solutions to a number of exceedingly difficult problems in order to build practical demonstration fusion power reactors toward the end of this century. Continued international collaboration is essential in fusion development. It is clear to us that no nation working alone is likely to deliver this vital energy alternative....

Recent Experimental and Theoretical Achievements

Let us now discuss how far we are from the goal. In the main we will base our conclusions on important experimental and calculational achievements of the last three years which give us confidence that fusion research and development is progressing in the proper direction....

PLASMA PARAMETERS IN TOROIDAL DEVICES

YEAR	τ_E SECS	T_I KELVIN	$N\tau_E$ CM^{-3}SEC	SUSTAINMENT TIME – SEC
1955	10^{-5}	10^5	10^9	10^{-4}
1960	10^{-4}	10^6	10^{10}	3×10^{-3}
1965	2×10^{-3}	10^6	10^{11}	2×10^{-2}
1970	10^{-2}	5×10^6	5×10^{11}	10^{-1}
1976	5×10^{-2} (T-10, PLT)	2×10^7 (TFR, ORMAK)	10^{13} (ALCATOR)	10^0 (T-10, PLT)
NEEDED FOR A REACTOR	10^0	10^8	10^{14}	$\gtrsim 10$

The continuing studies being made in learning how to generate and control plasmas is shown in the following summary of progress — the major plasma parameters since 1955. This summary was made at a recent fusion power meeting of the IAEA by Dr. Bas Pease, Director of the Culham Laboratory in Great Britain. It shows continuous almost exponential advance in all important fusion parameters (see fig. above).

.... In the last two years we have witnessed great progress in use of the well-mastered technology of relativistic electron beams to accomplish microexplosions. The main results here are the following:

1. It was experimentally proved that there exists a number of ways for magnetic focusing of electron beams on the surface of targets, providing sufficiently effective energy absorption.

2. A theoretical model (IAE) of the target was suggested in which the possibility is provided of electron energy absorption in the dense shell and the transfer of this energy in the form of heat, as in the laser target, for ablation and compression of the inner target and fuel.

3. Processes of energy absorption and transfer during acceleration of the shell up to the velocity of 10 million centimeters per second (that is only two times less than that required to initiate the fusion ignition), a thousand-fold compression of fusion fuel and its heating to kilovolt temperatures were verified experimentally. These measurements are confirmed by measurements of output and energy of fusion neutrons (1-3x106 per impulse in pure deuterium targets).

Thus, the main principles of electron beam compression is confirmed experimentally. Much research work on the study of all the main plasma and hydrodynamic processes, and comparison with calculations, lies ahead.

III. There is also progress in the field of magnetic compression of plasma targets though the combined experiment on plasma compression and heating by accelerated shells has not been carried out....

...In the near future it should be expected that a proof of principle experiment similar to those previously described for lasers and beams is be carried out.

Thus, there are three concepts in the field of fusion microexplosions — the use as an energy source of lasers, relativistic electron (or ion) beams, and magnetic fields. In all three cases approximately equal source power — 100 terrawatt — is needed. Less power is required with the use of magnetic plasma thermoinsulation in the target. From the viewpoint of reactor technology for the present, even in principle, we have no lasers with the necessary parameters — the high efficiency, the needed wave length and repetition frequency. The needed parameters of electron accelerators are state-of-the-art engineering. For systems with magnetic field we have magnetic compression generators with the necessary parameters, and inductive storages are in the process of development. The next few years will give us grounds to choose the leader among these three intertial confinement concepts.

A number of other programs are being developed in parallel with magnetic confinement systems and microexplosions. As experimental and theoretical material is accumulated in this field, it can be a source of new ideas or lead to significant improvements in already established concepts....

Fusion Technology and Design Development. Since the essential physical parameters necessary for creation of fusion reactors are being rapidly approached, technology and engineering should be developed in tandem to put these physics insights to practical use. Our fusion technology programs have made steady progress on many important engineering problems. In the field of stationary systems the solution of all problems is possible, in principle, on the basis of modern levels of technology, but significant efforts are necessary...

So, in the field of stationary systems we have established the major elements needed for future reactors. Extrapolation of progress in these developments permits us to hope that applying appropriate efforts we shall reach in time the technological level needed for creation of the reactor.

....

In such a way, at the beginning of the eighties we should obtain in tokamaks plasmas with parameters sufficient from the physics viewpoint to build reactors. Within the field of microexplosion, understanding the main physical principles have to be confirmed and theoretical and experimental principles have to be established. It is possible that fast progress in this field will permit proceeding to the next phase.

Next Generation Devices

We are prepared now to take the next steps to larger machines capable of producing sizeable quantities of fusion energy. Important milestones in the short run are:

1. The production and understanding of reactor-level hydrogen plasmas in 1979-1980.

2. The production of substantial quantities of fusion thermal energy by 1982.

ın the USSR the project of another prototype experimental fusion reactor — Tokamak T-20 — is being developed. This device is designed for longer operation nearly at the ignition threshold of fusion reaction in a D-T mixture. In this manner it will be able not only to study the ignition mechanism but to carry out tests of reactor construction material, elements of energy conversion system, etc. The main parameters of T-20 are: major radium-5m, minor radium-2m, the toroidal magnetic field-35 kg, the impulse duration of current 5-20 sec, the power of additional plamsa heating systems (the beam and high-frequency heating) - 50 MW, the mean ion temperature- 7-10 KeV. This installation will probably be put into operation in 1984-1985....

In addition, the conversion of "Angara-5" to the high repetition rate mode of operation (1 impluse per 10 sec) will enable us to solve a number of key questions of this approach such as the radiation and mechanical resistance of construction of the explosion chamber and energy blanket under conditions of great impulses....

Based on research results which are beyond the scope of this talk we can see that relaxation of assumed physics limitations may result in smaller and economically more attractive tokamak reactors. The next slide indicates the range of dimension from the earliest design concepts based on conservative assumptions to UWMAK III, the University of Wisconsin's latest study. The figures for PEPR-ITR and EPR come from preliminary studies performed at Oak Ridge and reflect changed views on scaling, beta, first wall life and better understanding of MHD instability.

There is another point of view on a fusion reactor economy popular in particular in the USSR. It is known that the atomic power industry on the basis of existing reactor-breeder types cannot be developed to the needed level without production of artificial nuclear fuel — plutonium or U-233. The reactor-breeders, because of their low production of commercial plutonium, cannot provide for a high rate of increase in electric utility development. Hybrid reactors offering high plutonium production are capable of converting the nuclear systems to plutonium fuel without a high investment in a uranium base development.

As far as the need for plutonium fuel can be answered at the cost of a few hybrid systems, fusion hybrids can turn out to be economically profitable despite high cost of a fusion reactor program.

International Support

Extensive collaboration exists among all the nations active in fusion R and D over 20 years. The beginning of this collaboration was initiated by I.V. Kurchatov, who in 1956 for the first time made a report on the Soviet fusion program at Harwell. This cooperation is affected through bilateral agreements, both formal and informal, for exchange of information and manpower, through multilateral arrangements facilitated by the International Atomic Agency.

A particularly close collaboration has arisen between the US and the USSR during the past three years. Both national programs consider the "tokamak" type system as priority. L.A. Artzimovich was prominent in popularization of this system in the United States when he gave a course of lectures on this subject in 1969 in the USA. This joint presentation today is evidence of the extensive communication and mutual support exchanged between our two national programs. Our exchange agreement is supervised by a group called the Joint (US-USSR) Fusion Power Coordinating Committee. By collaborating we have gained much technical knowledge. More important, we and our colleagues have learned to advance our programs in complementary steps. Although neither program is dependent on the other, our discussions and exchanges are undoubtedly increasing the probability of success in the overall effort.

Besides the programs of the US, the USSR, the Euratom countries and Japan there are several other national efforts which contribute materially to progress in fusion energy development.

Although we may not know the final form which fusion power reactors will take, we are confident that safe, economical fusion power will become a reality, and that the achievement of practical fusion power will be materially advanced — at a lower cost — by increasingly close multi-national collaboration as fusion development moves from plasma physics research into reactor engineering.