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The European Great Projects

In Rome on 26-27 March some 250 physicists from a wide range of specializations and from all the countries represented in the European Physical Society, assembled in Rome to listen to lectures on the main projects in physics that will have a strong influence on future developments over the remainder of the century.

This new initiative in bringing together the various branches of physics was recognized as an outstanding success. The lecturers were of high quality — the audience also and the universal consensus was that this must not be an isolated occasion.

Exchanges in the corridors were animated and constructive and if at first, discussions during the formal part of the Seminar were restrained, towards the end, the interaction was beginning to diverge and real issues were being raised that will not be allowed to die. For example: what structure should a centre housing a European Synchrotron Radiation facility have ? Questions such as this are questions of substance that the whole community of physics wants to discuss.

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Fusion Programme of Western Europe

Some highlights from the paper presented by D. Palumbo, Director of the Fusion Programme within the European Commission's Directorate General for Science, Research and Education.

The cross-section of the D-T reaction (which reaches a maximum of approximately 5 barn at about 100 keV) is such that the only way of achieving useful energy generation is by bulk heating of a deuterium-tritium fuel up to temperatures of around 10 keV or 100 MK. Elementary considerations of the energy balance lead to the Lawson criterion that for net electrical power production :

$n\tau > [(1-\eta)/\eta]\ [12\ kT / < \sigma v > Q_F]$

where n is the nuclear (and electron) density, τ is the confinement time, $<\sigma v>$ is an average on a maxwellian velocity distribution at a given temperature T, and Q_F is the energy output per fusion reaction. At a temperature of 10 keV and optimistic conversion efficiency η, of 0.3,

then $n\tau > 2 \times 10^{14}\ cm^{-3}\ s$

The condition of ignition, in which the reacting plasma is heated by the α-particles produced, is obtained by putting $\eta = 0.2$ in the above relation. Unavoidable radiation losses impose, even for a perfectly confined plasma, a minimum ion temperature of around 4 keV. Impurities of higher atomic number increase this temperature because of the rapid increase in bremsstrahlung radiation with Z.

A consequence of the Lawson criterion is that for inertial confinement systems, $n > 10^{24}\ cm^{-3}$ and τ is around 10^{-10}s, whereas for a magnetically confined plasma system, $n \sim 10^{14}$ - $10^{15}\ cm^{-3}$ and τ is of the order of seconds. In inertial confinement, where power densities are about 10^8 TW/cm^3 and pressures 3 x 10^{10} atm, one has a real micro nuclear explosion and certain States have been reluctant to cooperate internationally on a system which is so close to a military application. As a result, the western European fusion programme has concentrated mainly on magnetic confinement where, with power densities of a few W/cm^3 and pressures of some tens atm, the military implications seem non-existent.

European Coordination

In the fusion field, cooperation was begun by Euratom, following its foun-

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Table I. Expenditure break-down of the coordinated programme.

Expenditure, M ECU	Overall	Commission	
General support	616	154	25 %
Preferential Support	120	54	45 %
JET	180	144	80 %
Mobility of Personnel	2	2	100 %
Management, Admin.	7	7	100 %
	925	316	

dation on Jan 1, 1958, first through an association with the CEA in France in 1959. It has grown progressively to take in laboratories from all the members of the European Communities with the exception of Luxembourg and Ireland, plus recently Sweden and Switzerland. Until JET, cooperation took the form largely of coordinating and supporting the work undertaken in national laboratories (the Associated Laboratories) although some technological work was performed in the Euratom Joint Centre.

Currently the overall programme occupies about 900 physicists and engineers including about 120 Euratom staff most of whom work in the Associated Laboratories and on JET. Overall expenditure in the proposed programme for 1979-83 will total 925 M ECU of which the participation of the Commission of the European Communities adds up to 360 M ECU. In Table I is given the break-down of this expenditure which shows that JET, whilst an important component, is by no means dominant and even in the Commission's budget, represents less than half the total outlay.

Euratom has for some years adopted a policy of encouraging coordination by making important contributions (45 %) to new capital projects that are approved by the scientific community. It has been sucessful in establishing through its administration and its financial policies a rational programme of work in now 13 different laboratories. The question was raised at the conference whether too much attention was not being paid to large machines and too little to fundamental research. The response was that, in fact, a great deal was still being done with quite modest devices and there was still plenty of scope for purpose- built Tokamaks, within a coordinated programme. Fundamental research at the Universities might still contribute but a random attack on the problems was inefficient and it is necessary that work for the programme is done in conjunction with the big laboratories. It is perhaps worth emphasizing that the fusion programme as at present conceived, is expressly designed to achieve the practical result of power generation. Research is directed towards this goal only and is not supported for its inherent academic interest.

While useful plasma diagnostics can still be performed on smaller devices, large devices have to be built to obtain long confinement times. Empirically it has been found after experiments covering a wide range of parameters, that confinement time is proportional to the square of the torus minor radius, independent of the toroidal field, whereas classical theory would indicate that it was proportional to the square of the product of the field and radius. If this is to the disadvantage of the programme in putting a premium on size, there is consolation in the fact that confinement time seems proportional also to plasma density rather than inversely proportional as classical analysis would suggest.

A problem facing the Communities is the gearing of programmes to a five-year plan following which there can be a discontinuity before the start of a new period. In the case of fusion, however, two political decisions of great significance have been taken, notably :

1) Each 5-year programme is "part of a long-term cooperative project, embracing all work carried out in the Member States in the field of fusion and plasma physics. It is designed to lead in due course to the joint construction of prototypes with a view to their industrial scale production and marketing" .

2) After three years of implementation of each 5-year programme, a new 5-year programme must be prepared.

Fusion is thus being pursued with an awareness that the cooperation must go on right through the commercial exploitation and not go by default when the industrialisation stage is reached.

JET is the first "joint undertaking" of the Communities in this evolution. Its objectives can be summarized as follows :

1) Analysis of the behaviour of the plasma when the parameters approach those of the reactor working domain.

2) Study of the plasma-wall interaction under these conditions.

3) Study of plasma heating.

4) Study of the production and confinement of alpha particles and the resultant plasma heating.

5) General studies such as plasma formation and shaping.

European Machines

Progress over the past years in increasing temperature and confinement time has been steady, as can be seen from Table II, and the requirements for a reactor no longer seem so remotely distant. Since 1968 when the Russian experiment T-3 established a solid basis for belief in the Tokamak configuration, a number of new machines have been built in Europe which have advanced the art. Characteristics of the principal machines are given in Table III. Pulsator at Garching gave fundamental information on high density limits and stability. TFR at Fontenay-auxRoses was from 1973-1976 the most powerful machine in the world and attained, with neutral injection supplementary heating, a temperature of 2 keV; in a new version it has successfully demonstrated cyclotron resonance RF heating. FT at Frascati has recently been working with $n\tau$ in the range of 10^{13}. DITE at Culham is designed to generate plasma of exceptional purity and is equipped with neutral injection additional heating.

Supplementary heating is now recognized to be essential and two main groups have been established to tackle respectively : neutral injection (led by Culham and Fontenay-aux-Roses) and radio frequency heating (led by Grenoble) in which area the machine WEGA is a joint venture of Garching, Grenoble and ERLM, Brus-

Table II. Progress towards fusion conditions.

Year	τ_E, s	T_i, K	$n\tau_E$, cm^{-3}s	Sustainment Time, s
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}	2×10^7	10^{13}	1
1978	8×10^{-2}	6×10^7	2×10^{13}	1
Reactor requirement	1	10^8	10^{14}	10

sels. The second generation of machines now under construction (see Table II), ASDEX in Garching and TEXTOR in Jülich are directed towards research into particular aspects of Tokamak behaviour whereas the first generation machines were more general Tokamak physics research tools. ASDEX will concentrate on plasma purity and TEXTOR on plasma-wall interaction.

While most of the European programme is concentrating on Tokamak development, there is still on-going research into stellarators of which two may be mentioned : CLEO at Culham where, in collaboration with Padua the reversed field pinch is being studied too, and Wendelstein VII at Garching, currently the largest stellerator in the world.

In the USSR, it seems likely that the very large Tokamak T-20 will not now go ahead, as recent progress and other projects have diminished its usefulness. Instead, the USSR is promoting through the IAEA in Vienna the construction of a world machine following the initiative of Sigvard Eklund, the IAEA's Director-General. Japan is expressing considerable interest and it would seem that so far western Europe has shown the least enthusiasm, possibly because of exhaustion from the long drawn out negotiations on JET. A world project is, nevertheless not just empty talk and studies are beginning on what should be built. The USSR has a vigorous programme of work on Tokamaks, including about ten at Novosibirsk doing physics, and the abandoning of T-20 signifies no lack of interest in the system.

Table III. Characteristics of European Machines.

Machine	Location	*R*, cm	*a*, cm	*B*, T	*I*, kA
T-3	USSR	100	15	3.5	120
Pulsator	FRG	70	12	2.8	95
TFR	F	100	20	6.0	400
FT	I	83	21	10.0	1000
DITE	UK	117	27	2.8	250
ASDEX	FRG	164	40	2.8	500
TEXTOR	FRG	175	50	2.0	500
JET	UK	296	125/210 *	2.8-2.5	3800-4800

R = major radius of torus : , a = minor radius
B = toroidal field ; I = plasma current

* D-shaped ring

Technology

Once the basic physics problems of a fusion reactor have been solved there will still be major areas of technology that need to be tackled. Satisfying the Lawson criterion is just the beginning. Of particular difficulty is the choice of structural materials for plasma boundary blanket and shielding, which are subjected to a massive fast neutron fluence. Another area is the question of tritium management in a circuit where the inventory might be of the order of 1 kg/GW (th). Again the problem of producing the big magnetic fields economically, imposes superconducting technology which is still in its infancy.

Work is only just beginning on a collaborative basis in these areas and there is obviously much scope for further development. Agreement has been reached with the USA for joint work on materials, using an American high flux neutron source, and implementing agreements have been concluded with the USA and Japan for cooperation on superconductors.

When

Multi mega dollar question to Palumbo was when we might expect to see thermonuclear power becoming competitive. Refusing to be drawn so far, he was nevertheless prepared to guess that we might have a demonstration reactor working at the beginning of the next century.

Some Large Projects in European Astronomy

Extracts from the paper presented by L. Woltjer, Director-General of the European Southern Observatory, a collaboration of the following countries: B, DK, F, FRG, NL, S.

Optical Telescopes

Progress in optical astronomy over the past sixty years has not come about by building ever larger telescopes but in particular by improving the detector efficiency. In 1920, already one telescope of 2.5 m aperture was in operation and in Table I it can be seen that the majority of those telescopes completed recently and planned for the immediate future have apertures that are not very much larger. Recent telescopes in the USA have followed the same pattern; the Kitt Peak and Cerro Tololo instruments each have an aperture of 3.8 m. Now that detectors have reached a photon collection efficiency of around 50%, further improvement where the limitation is imposed by the faintness of the photon flux, can only come from larger detection areas. Angular resolution may be obtained in various ways, especially through interferometry and for the very faintest objects where detection is limited by the background, it is necessary to go out into space.

Table 1. European optical telescopes of recent years.

Observatory	Location	Country/Org.	Aperture, m	Completion Date
Siding Spring	Aus.	UK-Aus.	3.9	1974
La Silla	Chile	ESO	3.6	1976
Zelenchukskaya	USSR	USSR	6.0	1977
	Hawaii	Can.-F-Haw.	3.6	1979
Calar Alto	Spain	FRG	3.5	1982
	Canaries	UK	4.2	
		Italy	3.5	
(Infrared	Hawaii	UK	3.8	1978)

Because of the brightness of the night sky, which on a lonely mountain top still amounts to 1/4 of a 20th magnitude stars / (arc s)^2, stars much fainter than the 25th magnitude are essentially out of reach of terrestrial telescopes. Minimum size of a point-like object due to atmosphere disturbance it should be noted is 1-2 arc s. Hence the need for the Space Telescope which is a joint project of NASA (85 %) and ESA (15 %). The ST is a 2.4 m aperture telescope with optics close to the diffraction limit, giving a point stellar image of 0.15 arc s. A further gain comes from the background, lower by one magnitude (factor 2 $^1/_2$) than at the best terrestrial observatory. With such an instrument, point-like objects down to the 29th magnitude can be detected. Moreover, its ultraviolet capabilities and high angular resolution are of great importance.

Where however the limit is not background, but the smallness of the number of photons, as for example in