desirable to demonstrate superiority to fission and to avoid future backfits, but higher dose targets are desirable to prevent future regulations from becoming too stringent and to contain costs.

WASTE MANAGEMENT: S. CIATTAGLIA, CHAIR

P. Rocco (CEC) discussed fusion reactor waste classification and management. Near surface burial is unlikely. He recommended classifying medium-level waste (MLW) as having contact dose rates between 2 and 20 mSv/h and heat generation rates between 1 and 10 W/m^3. Waste below or above this range would be low-level waste (LLW) or high-level waste (HLW). For an ideal fusion reactor, the first wall and divertor would be MLW, and everything else would be LLW. Use of LAMs is desirable to avoid generation of HLW. K. Broden (Sweden) discussed the quantification, treatment, packaging, and disposal (divided into shallow burial and geological disposal) of potential waste products from the NET experiment (70 kt with activity 70 PBq after 50 yr of interim storage). That waste could be accommodated in German repositories (Gorleben and Konrad) or in Swedish repositories (Subseabed Forsmark Repository under the sea and SFL-3).

W. T. Shmayda (Canada) discussed outgassing from tritiated stainless steel. During a furnace temperature ramp, the vapors emitted from the steel (mainly water) were trapped in bubblers then processed and analyzed. The thermal desorption spectra were reproducible but varied with service conditions (such as oil on samples) and storage times.

The generation of HLW should be avoided for public acceptance and lack of a repository at present. Each country should foresee a final repository. Plans for easy decommissioning and waste reduction should be initiated early in the design. We should exploit knowledge gained from fission reactor waste management and decommissioning.

CONCLUSIONS

The strong emphasis given to safety is a credit to the IAEA and ITER leadership. By the time of the next meeting in this series (in about 1996, possibly in Japan) the ITER EDA will have determined the major ITER parameters, and the safety analyses will be more refined. International cooperation, as exemplified by this meeting, will help guide the ITER project toward an experiment that can win public confidence. Optimization of safety may be crucial to the successful development of fusion power.

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SUMMARY OF THE 20TH EUROPEAN PHYSICAL SOCIETY CONFERENCE ON CONTROLLED FUSION AND PLASMA PHYSICS, LISBON, PORTUGAL, JULY 26–30, 1993

INTRODUCTION

The conference was organized by the Sociedade Portuguesa de Física and the Centro de Fusão Nuclear on behalf of the European Physical Society (EPS). It was attended by about 470 physicists from 40 countries. More than 100 participants were from outside Europe, in particular from the United States (50) and Japan (over 30). Also, a significant number of scientists (~30) came from Russia.

The program included 27 invited lectures and 370 contributed papers, which were either oral or poster presentations. The poster presentations are contained in *Europhysics Conference Abstracts*, Vol. 17C, Part III, Lisboa, July 1993 (J. A. Costa Cabral, M. E. Manso, F. M. Serra, and F. C. Schüller, Eds.). The invited lectures are expected to appear toward the end of 1993 in the journal *Plasma Physics and Controlled Fusion*.

The following topics were presented at the conference (the number of contributions is in parentheses):

1. tokamaks (83)
2. stellarators (25)
3. alternative confinement schemes (30)
4. plasma edge physics (73)
5. heating and current drive (55)
6. diagnostics (45)
7. inertial confinement fusion (ICF) (7)
8. general plasma theory (56).

FUSION REACTOR: NEW ITER AND ALTERNATIVE SOLUTIONS

A note of lasting controversy was introduced in the first presentation of the conference. In his invited talk, R. Parker, deputy director of International Thermonuclear Experimental Reactor (ITER)–Engineering Design Activities (EDA), Garching, outlined the partly new guidelines of the ITER task, namely,

1. safe extrapolation from present machines ("ITER must work")
2. reactor-relevant technology wherever possible
3. demonstration of economic fusion ("potential for attractive cost of electricity")
4. compared with fission, demonstration of easier waste disposal
5. simplicity of construction.

These highly ambitious requirements of ITER resulted in a substantial increase of the geometrical and technical machine parameters. Table I shows the major differences between the previous conceptual design [ITER–Conceptual Design Activities (CDA)] and the new values, together with those of a possible advanced tokamak reactor alternative.

TABLE I

Major Differences Among Next-Step Devices

	ITER-CDA	ITER-EDA (New)	"Steady-State Tokamak Reactor"
I (MA)	22	25	12
B (T)	4.85	6	9
R	6	7.75	7
a	215	2.8	1.7
Bootstrap current fraction (%)	~30	~30	75
$\tau_E/\tau_{E'89}$	~2	~1.4	~2
Fusion power (GW)	1	1.5 to 3	3
Mode	Pulsed/steady	Pulsed	Steady

While the increase in plasma current, magnetic field, and linear dimensions essentially results from the first of the foregoing options, the demonstration of economic viability and environmental safety seems to require innovative solutions for wall and blanket concepts. Therefore, it is planned that a vanadium alloy (vanadium-chromium-titanium) will be used for ITER in combination with liquid lithium cooling and breeding in the blanket.

According to Parker, this concept would accommodate the three times larger power flux (~3 MW/m^2 neutron flux), which is a prerequisite for cheaper fusion power, and it would also reduce the radioactivity cooldown time by one order of magnitude, which is needed to demonstrate the environmental advantage of fusion. Parker's answer to critical questions and concerns that such a step may be too large and risky was that when ITER is finally in operation, it will be measured against the concurring energy schemes 10 to 15 yr from now, and fusion will lose if based on present-day technologies.

The present ITER line (i.e., large-size, high-current, and pulsed concept) as a step toward a demonstration reactor (DEMO) and, finally, to a power reactor, was questioned by Kikuchi (Japan Atomic Energy Research Institute), who presented in his invited talk the steady-state advanced tokamak reactor as a possibly more attractive alternative. Its basic features, as shown in Table I, are the much smaller current from which only a small fraction ($\sim\frac{1}{4}$) must be driven by external means (in this case by 2-MeV neutral beam injection). However, whether the key assumption for such an "advanced concept," namely, high confinement at low current and large bootstrap contribution, can be realized in a steady-state mode seems to have been an open question until now and must be explored in appropriate experiments.

In a third invited lecture on the same topic, B. Tubbing [Joint European Torus (JET)] tried to make the trade-off between the two controversial approaches to the tokamak reactor. He outlined that the conventional high-current device necessarily must be operated in a pulsed mode in order to keep the recycled power below the ~20% limit. The basic disadvantage of pulsed operation may, however, be overcome by an appropriate energy storage system in combination with some reduction of the maximum stress parameters of the machine. According to Tubbing, for such a reactor concept, the cost of electricity would exceed that of an "advanced" steady-state reactor by only a small amount. If, alternatively, a high confinement mode at low current and high bootstrap fraction could be realized, pulsed operation using inductive current drive would be the more economic solution. Nevertheless, in view of the still open fatigue problem, Tubbing stated that a detailed study of a pulsed DEMO reactor is urgently needed.

TOKAMAKS

Impressive new results were reported by O. Naito from the largest Japanese tokamak, JT 60-U, after its modification. According to Naito, the fusion product $n_D(0)\cdot\tau_E\cdot T_i(0)$ could be increased by more than a factor of 2 to 1.1×10^{21} (m$^{-3}\cdot$s$\cdot$keV), exceeding that of JET. In the high-β_p experiments, the stored energy could be ramped up to 8.7 MJ by the available plasma heating power of over 30 MW.

Progress toward the steady-state tokamak reactor (as outlined by Kikuchi) was demonstrated by the quasi-steady discharges of very high Troyon-β and β_p values ($\beta_N \lesssim 4$, $\beta_p \lesssim 4.3$) with a bootstrap current of ~50% and good confinement ($\tau_E/\tau_E^{ITER} \sim 1.5$ to 1.8) at ELMy mode operation.

These claims, however, must be reviewed in perspective since many of the conditions cannot be maintained in a reactor: The ultimate parameters apparently require a broad pressure but a peaked current profile, the latter transiently achieved by current rampdown with q values of ~8 to 14. Broad-broad or peak-broad p/j profiles resulted in diminished plasma performance (β_N and β_p about one-half the foregoing values). Furthermore, the high bootstrap contribution (up to 40%) may be the result of the intense particle source of ~30-MW (low-energy) neutral beam injection, which may not be available under reactor conditions.

Thus, the unequivocal experimental verification of the advanced tokamak concept remains a challenging task for the future.

Among the other large tokamaks, ASDEX Upgrade is of special interest because of its topological similarity to ITER. The first detailed results of edge physics and H-mode operation were presented by M. Kaufmann. Notable for this device is the easy H-mode access occurring at one-half the usual ($B\cdot n_e$) value, leading to H-mode operation in purely ohmic discharges. A transition to cold divertor operation mode as a major goal of ASDEX Upgrade could be achieved close to the density limit. For these high-density conditions at the target plates, tungsten atoms eroded from a small test area were found to be completely redeposited without lateral displacement, which can be explained by a sufficiently short ionization length ($\lambda_{ion} < r_{gyro}$). During the transition from hot to cold divertor plasma, on the other hand, no change in the carbon impurity content was found. In conjunction with spectroscopic measurements, it was concluded that chemical erosion from the carbon walls in the main chamber is responsible for this principal impurity, a result that might be of concern for future machines.

In a further invited talk, O. Gruber summarized observations of vertical displacement events (VDEs) and halo currents obtained in ASDEX Upgrade so far. According to Gruber, up to 40% of the plasma current may be transferred into halo currents that for ITER parameters would result in forces of the order of 10^4 tons acting on the vessel. The apparent problem, nevertheless, seems to be somewhat relaxed because of the observed short quench time of the halo currents. A numerical modeling of the VDE process, which would also allow extrapolation to larger devices, is under way.

From the other large tokamaks [DIII-D, Tokamak Fusion Test Reactor (TFTR), TORE Supra], further progress in the area of plasma heating and pellet-related confinement physics was reported.

During this time, JET was incapacitated by its long shutdown phase for divertor implementation. A detailed analysis of former data, however, resulted in a rather exciting observation in the area of transport physics: The change in the local χ_E value due to L-H-mode transition was found to occur almost instantaneously throughout the entire plasma cross section. This would mean that anomalous local transport does not depend on local parameters, such as T_e or ∇T_e, etc., which remain absolutely constant during the <1-ms time scale for the observed χ_E change (poster by S. V. Neudatchin).

A strong case for the importance of "small tokamaks" for fusion research was made by D. C. Robinson (AEA Culham) in his invited lecture. According to Robinson, these devices, defined by a current below 300 kA and dimensions of $R <$ 1 m and $a < 0.25$, are well suited (and needed) in order to explore wider parameter ranges or new ideas. He quoted as typical examples aspect ratio scaling from large values down to an almost spherical $[A \sim O(1)]$ configuration, a highly elongated plasma shape, ergodic divertor, high-β/second stability investigations, test of new control techniques, and many other important contributions. Another important role of these 26 devices is seen by Robinson to lie in their potential training and education of young scientists in various countries.

STELLARATORS

One experimental and two theoretical lectures were dedicated to the stellarator topic. In the experimental paper on the "first results of Uragan-2M" by O. S. Pavlichenko (Charcov), only a summary of the design parameters of this new torsatron "with reduced helical ripple" ($R/a = 1.7/0.22$ m; $B \leq$ 2.4 T; heating up to 5 MW) *together with first flux surface measurements* was available at the time of the conference.

New interesting results were reported in some contributed papers. Long-pulse operation (~1.1 s) with a new 140-GHz/0.5-MW Russian prototype gyrotron and further H-mode experiments were reported by V. Erckmann from the W7-AS stellarator.

The observation of an ultrafast (<1 ms) change of the anomalous transport coefficient in case of a fast variation (rectangular modulation) of heating power, also on W7-AS (U. Stroth), seems to be a significant result. Such behavior, now observed in the case of a stellarator, can be seen in connection with a similar fast transport change reported from a tokamak (JET) and may help to gain insight into the mystery of toroidal transport.

The whole area of plasma transport in ("advanced") stellarator geometry was surveyed by H. Maaßberg [Institute for Plasma Physics (IPP), Garching]. In the second theoretical stellarator lecture, J. Nührenberg (IPP) gave a comprehensive introduction to the magnetohydrodynamic (MHD) aspects of the various stellarator approaches.

ALTERNATIVE CONFINEMENT SCHEMES

In an invited talk, V. Antoni reported on recent results of the Reversed Field Pinch Experiment (RFX) in Padova. Supplemented by a series of contributed papers, this survey gave the impression of a substantial extension of the parameters achieved so far. Looking more closely, however, even at maximum current (~700 kA, resulting in ohmic heating of almost 30 MW), quite poor plasma confinement was still observed: At central temperatures of ~250 eV, the confinement time was in the range of 0.6 to 1 ms only. The discharge, furthermore, suffered from the large impurity release from the carbon walls producing a $Z_{eff} \sim 4$ to 5.

In view of these modest parameters and the obvious plasma-wall problem, with no divertor-type solution in sight, the prospects of the RFX concept for reactor application do not seem convincing yet.

PLASMA EDGE PHYSICS

For the first time, the major part of EPS contributions was dedicated to edge physics problems. New results on edge transport and its modeling were reported from all major divertor or (pumped) limiter machines, tokamaks as well as stellarators. Specifically to be noticed here was the detailed discussion of how bias fields can be used to influence or eventually control the edge (invited talk by R. R. Weynants). Also of interest is the progress in establishing a stable radiating edge region, as achieved in Tokamak Experiment for Technology Oriented Research (TEXTOR) by silicon or neon doping (invited talk by U. Samm). According to Samm, up to 80 to 90% of the outward power flux could be transferred into edge radiation without affecting the bulk plasma noticeably, a technique that may solve or at least ease the power exhaust problem in a reactor.

The apparent divertor problem in the reactor was discussed by G. Vlases. In his excellent survey on divertor physics, he first introduced the fundamental difficulty that the width of the outcoming plasma fan is too small, which, under reactor conditions, may result in power fluxes of as much as 100 MW/m^2. A "dramatic increase" of the "wetted" area would be the basic solution for which the various possibilities were analyzed in detail: production of a thicker scrape-off layer (SOL) (by increased perpendicular transport) and/or operation at extreme inclination of the target plates (e.g., down to nearly 1 deg), seeding of the divertor plasma with radiating impurities (which, however, must be kept away from the bulk plasma), and/or establishing a gas target for discharge exchange losses and eventually locating the divertor fan before the target plates (this, however, could produce too much erosion at the side walls). In conclusion, Vlases stated that a satisfactory simulation of an ITER divertor solution has not yet been produced, but "there seems to be some basis for optimism." Here, experiments on radiative and gas target divertors and on the SOL control are needed for model refinement and extrapolation to ITER.

HEATING AND CURRENT DRIVE

Plasma heating and current drive issues were discussed in one invited and in a large number of contributed papers. In his invited talk, M. Petilin (Institute of Applied Physics, Nizhni-Novgorod) gave a comprehensive overview of the "physics of advanced gyrotrons." According to Petilin, who is himself one of the few pioneers in this area, the progress in this most modern development in wave heating techniques appears remarkable. The Russian gyrotron concept of high-order volume mode in combination with a built-in "advanced" quasi-optical converter already reaches as much as 1-MW power at 140 or 166 GHz with more than 30% efficiency. In due time, i.e., for ITER application, the power could be raised to ~2 MW, possibly using a coaxial cavity, and the currently poor efficiency would be increased to the 50% range by depressed collector operation and by reducing the velocity spread in the electron beam.

According to experimental results, the high-power window, still a matter of concern, seems to allow CW operation up to 1 MW (edge cryo-cooled sapphire, 10-cm diameter).

Of the remaining contributions on the topic of heating and current drive, about two-thirds were dedicated to theoretical problems of plasma heating. The key themes included wave propagation in the various frequency regimes, current drive, synergetic effects in the case of combined lower hybrid and ion cyclotron operation, wave-induced transport, and others.

On the experimental side, progress of ion cyclotron resonance heating at TFTR was reported. A rather interesting heating, or more precisely diagnostic, experiment was performed at the W7-AS stellarator, where modulated electron cyclotron current drive (at 70 GHz) was applied symmetrically in co- and counterdirection. Using both microwave beams modulated in phase, the current drive contributions cancel, but the bootstrap current gets modulated according to the resulting power modulation. In out-of-phase operation, however, the net power remains constant, while the driven current fraction alternates its sign. From the respective amplitudes, the quantification of both the bootstrap current and the electron cyclotron-driven current as well as their localization were possible.

DIAGNOSTICS

As usual, the area of diagnostics was represented by a large number of individual contributions that cannot be discussed here in detail. First, direct measurements of the magnetic fluctuations in the plasma core may be mentioned here as an example of continuously progressing diagnostic techniques (X. L. Zou et al., TORE Supra). By using cross polarization scattering of X- and O-mode, the authors were able to detect the $\delta B/B$ values of the order of 10^{-4}, which might explain the anomalous transport.

Finally, in an invited lecture, M. E. Manso outlined various schemes and applications of reflectometry, which has tended to become a standard diagnostic in toroidal plasma confinement devices.

INERTIAL CONFINEMENT FUSION

In this invited lecture, M. M. Basko (Institute of Theoretical and Experimental Physics, Moscow) gave a comprehensive and critical overview of inertial fusion and its reactor prospects. After a brief introduction to the basic elements of ICF, such as the density times radius requirement ($\langle \rho \cdot R \rangle \gtrsim$ 2 to 3 g/cm^2), the required homogeneity of implosion (pressure deviation $\Delta P/p \lesssim$ 2 to 3%), and the resulting energy input, he derived the minimum tolerable product of driver efficiency and fusion gain ($\eta_{driver} \cdot G) \gtrsim 10$.

After a detailed comparison of the various concepts, "spark" (i.e., centrally localized) versus global (homogeneous) ignition and direct versus indirect pellet drive, Basko tried to evaluate the present state of the art and reactor prospects for ICF. He stated that ignition can be expected within the next program step of laser fusion. Before the year 2000, it should be possible to achieve this goal in the Omega-Upgrade facility with ~30-kJ laser energy.

A further statement, however, was that laser fusion will not be suitable for electric power production because of its poor product of driver efficiency times fusion gain ($\eta_{drive} \cdot G$). This approach, nevertheless, may be of importance for ICF microimplosions, which according to Basko would be "rich in applications."

For reactor operations, the use of heavy-ion beams, while currently still in an exploration phase, could ultimately achieve the requirements for economic power production. Here, Basko's still somewhat cautious conclusion was "In what concerns heavy-ion drive, the basic programme of ICF target experiments is yet to be formulated."

GENERAL PLASMA THEORY

Although this journal is not primarily a technically oriented one, attention may be given to a few theoretical contributions. First to be mentioned here is the invited lecture by D. Montgomery (Dartmouth College, United States), who gave an interesting overview of dimensionless variables and their importance for the understanding and extrapolation of plasma confinement.

Also of interest was the contribution by J. Goedbloed (FOM Institute for Plasma Physics, The Netherlands), who outlined the possibilities of an "MHD spectroscopy," i.e., to diagnose the various MHD modes [e.g., ELMs, toroidal Alfvén eigenmodes (TAEs)] by applying appropriate rf perturbations.

The fast alpha-particle-induced turbulence (TAEs) was discussed by F. Zonca (Comitato Nazionale per l'Energia Nucleare e Alternativa, Italy), and the complex behavior of fast particles in toroidal geometry was surveyed by J. M. Rax (Centre d'Études Nucléaires, France).

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SUMMARY OF THE INTERNATIONAL SYMPOSIUM ON HEAVY-ION INERTIAL FUSION, FRASCATI, ITALY, MAY 25–28, 1993

INTRODUCTION AND PERSPECTIVE

The 1993 International Symposium on Heavy-Ion Inertial Fusion was the sixth in a series initiated in Darmstadt, Germany (1982) and followed by meetings in Tokyo (1984), Washington, D.C. (1986), Darmstadt (1988), and Monterey, California (December 1990). The symposium was sponsored and hosted by Ente per le Nuove Tecnologie, l'Energia e l'Ambiente (ENEA) (the Italian national agency for energy, new technology, and the environment) and organized jointly by ENEA and the Italian Physical Society.

The purpose of the symposium was to provide for the international exchange of information on the physics, the experimental techniques, and the technology of relevance in the field of heavy-ion inertial fusion.