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.

The meeting was attended by about 100 scientists and engineers from nine countries (in order of attendance: the United States, Germany, Italy, France, Japan, Russia, Switzerland, Israel, and Spain). The program consisted of 5 reviews, 20 invited and 6 contributed talks, and 58 poster presentations (in the three sessions). The presentations dealt with the large spectrum of scientific and technological problems of such an interdisciplinary topic as heavy-ion fusion (HIF), with a reasonable balance between driver (accelerator) and target issues and, as far as possible, between experimental and theoretical work. Indeed, a peculiar aspect of this series of symposia, and probably the key to its success, is the opportunity it provides for cross-fertilization between communities with different expertise and, in particular, for stimulating critical studies in crucial interface areas.

Heavy-ion accelerators are now regarded by many as the principal driver candidate as inertial fusion energy driver. This position was held by the final reports, released in 1990, of two high-level U.S. committees: a National Academy of Sciences committee [which reviewed the U.S. Department of Energy (DOE) Inertial Confinement Fusion (ICF) Program[1]] and the Fusion Power Advisory Committee.[2] The latter, in particular, supported funding a specific DOE inertial fusion energy (IFE) program, in large part dedicated to heavy-ion accelerators. The stand of HIF as the leading candidate for IFE is due to the anticipated high repetition rate and the relatively large efficiency of heavy-ion accelerators as well as to the reliability demonstrated by the existing large accelerator systems. In addition, good ion beam-matter coupling is expected. Target studies, also supported by the large data base accumulated in two decades of laser fusion experiments, indicate the possibility of achieving a target gain adequate for energy production.

However, many scientific and technological issues still require considerable research and development, in particular because of the large extrapolation of parameters from the present-day devices to the anticipated reactor driver and also because of the lack of experimental demonstration of some crucial aspects, such as certain beam manipulations, the final beam focusing, and several target issues.

In his welcome address, the symposium chairman, R. A. Ricci, noted that despite the promises of HIF and the quality of past and ongoing research, the development of the field is limited by the present modest level of funding and by the uncertainties for the future. On the other hand, particularly in Europe, the appealing features of HIF have attracted in the past 2 yr the interest of part of the large accelerator community and of several inertial fusion groups. The full utilization of such valuable expertise requires the setup of a framework for international cooperation.

Since the December 1990 Monterey Symposium (see Ref. 3), significant progress has been made in many areas, new topics have been addressed, and shifts of emphasis have occurred in other areas. In the United States, where the induction accelerator approach is pursued, after successful completion of the MBE-4 experimental program, efforts concentrated on designing the Induction Linac System Experiment (ILSE), on system studies for recirculating induction accelerators and on technological developments for accelerator components. ILSE (see below) should demonstrate (in a scaled-down environment) all beam manipulations required in a reactor driver. Elsewhere, the radio-frequency (RF) linac and storage rings approach is followed. The large heavy-ion accelerator SIS-ESR is now routinely operating at the Gesellshaft fuer Schwerionenforschung (GSI), Darmstadt; it allows for routinely performing experiments on the dynamics of space-charge-dominated heavy-ion beams in storage rings and, in the near future, on fusion relevant intense beam/matter interaction. New technical solutions for transporting the required space-charge-dominated currents have been proposed. Studies on the crucial issue of final focusing have been performed. In the meantime, laser fusion programs (mainly in the United States and in Japan) have resulted in substantial advances in such HIF-relevant target physics topics as hohlraum physics and target stability.

At the 1990 Monterey meeting, it became apparent that the European groups had turned their attention to indirectly driven targets, but the relevant analyses were mostly of a qualitative nature. Since then, several details of the physics of such targets have been studied. Alternate target concepts have also been analyzed. Consequences for accelerator design have been more carefully evaluated.

RUBBIA'S OPENING TALK

A perspective to the symposium was provided by the opening talk by C. Rubbia (CERN, Geneva). He asserted that, just as for any other new energy source, the success of heavy-ion inertial fusion will depend on economy and social acceptability. Technical solutions leading to simple, highly reliable, small-size power plants should then be looked for. In his opinion, avenues exist for HIF to attain this ambitious goal. In particular, for the RF linac and storage ring approach, options to be considered for size and cost savings are the use of recently developed high-performance inter-digital H linacs (see below), the possibility of performing part of the acceleration in the rings, the use of bundles of beamlets manipulated by matricial structures and photo-assisted non-Liouvillian pulse stacking (proposed by Rubbia himself at the 1988 Darmstadt Symposium[4]). All these options deserve attention and require detailed analyses. As far as the target is concerned, crucial issues are the choice of the number and the geometry of the radiation converters. Also, relative merits of conventional hohlraum targets with concentrated converters[5] and of the targets with diffuse converters [also termed hotraum targets (see below)] should be assessed. The long-standing problem of the Rayleigh-Taylor instability still deserves attention. Finally, a topic that is crucial for any HIF approach and has not yet been addressed conclusively is the final focusing. This issue, with profound influence on the design of the driver, of the reactor chamber, and of the target, is somehow paradigmatic of the complexity and beauty of HIF research.

Rubbia also showed the tentative parameter lists for two drivers based on a scheme consisting of a source, followed by an inter-digital H linac (with accelerating potential of 4 MV/m), injecting the beams into N_{sr} storage rings, where the ion beams are accumulated and eventually accelerated. After compression, $N_b = 12$ separate bunches (straws) are extracted from each ring. The $N_{bt} = N_b N_{sr}$ resulting bunches are then merged and focused onto the target by suitable matricial focusing structures. The first driver delivers in 10 ns an energy of 6 MJ of 15-GeV bismuth ions onto the six tiny (0.8-mm radius) converters of a six-converter hohlraum; the second driver delivers the same energy and power in the form of 6-GeV bismuth ions onto the 5-mm spots of a hotraum target. In both cases, the linac injects a 1-A current in the storage rings, with the injection energy being 3.5 GeV in the first case and 1 GeV in the second one. Accordingly, the length of the linac and the radius of the rings are 880, and 200 m, respectively, in the first design, and only 250 and 100 m, respectively, in the second one. The number of storage rings are $N_{sr} = 12$ and $N_{sr} = 24$, respectively. These figures indicate that it might be possible to reduce the linac size by more than a factor of 5 when compared with more conventional schemes; overall efficiencies not far from 50% can also be foreseen.

Future experiments should test the potentials of these new proposals. To this purpose, in Rubbia's opinion, the progress of heavy-ion inertial fusion requires a new major experimental device capable of entering the ignition domain and complementing the Nova-Upgrade laser proposed by Lawrence Livermore National Laboratory (LLNL) as the U.S. National Ignition Facility[5] (NIF).

In the following, we summarize thematically the main results reported at the Frascati Symposium. Papers will be referred to by the name of the first author. The proceedings of the symposium will be published as a special referreed issue of *Il Nuovo Cimento A*, edited by S. Atzeni.

ACCELERATOR PHYSICS AND TECHNOLOGY

The general accelerator issue is the generation, transport, and focusing of high-current, low-emittance, space-charge-dominated ion beams. In two complementary review talks, R. Bangerter [Lawrence Berkeley Laboratory (LBL)] and I. Hofmann (GSI) discussed the design criteria, the main physics issues, and possible technical solutions for the induction accelerator approach and for the RF approach, respectively. They also outlined the ongoing U.S. and German accelerator activities, respectively. Details on many aspects have been provided by related talks and posters.

Induction Accelerators

The goal of the U.S. program is the demonstration of the feasibility of an induction linac driver. In their studies, U.S. researchers adopt the following set of reference standard parameters (about which in Bangerter's words they "are not obstinate"): they foresee two-sided irradiation of the target, with focal spots of radius $b = 3$ mm, by beams with total energy $E = 5$ MJ, with peak power $W = 400$ TW. Ions with mass $A \approx 200$ and kinetic energy $T = 10$ GeV, for which the range in light materials is $R \approx 0.1$ g/cm^2, are considered. The corresponding standard accelerator is a single-pass induction linac into which the source beams are injected at ~ 3 MeV (with a current of 1 A/beamline), then accelerated (and focused) electrostatically up to 100 MeV, and then 4:1 combined (achieving a current of 10 A/line); subsequently, they are accelerated and focused magnetically (10 GeV, 400 A) and, hence, are bent and eventually focused onto the target (4 kA/line).

Preservation of emittance and cost consideration furnish guidelines for the design, which were reviewed by Bangerter. Fundamental and technical limitations concern the maximum transportable beam current (Masckhe limit), space-charge effects, the transverse emittance, the ion source, the induction cores, etc. Current understanding supports the feasibility of the reference accelerator, but uncertainties exist in several areas. The experiments on SBTE and MBE-4 have been successful (having answered fundamental questions) but were limited to the first stages of the accelerator (source, injector, and electrostatic acceleration). To test all accelerator physics elements and all beam manipulations, LBL and LLNL have proposed and designed a new facility, ILSE. ILSE (also described by C. M. Celata et al.) is a scaled-down facility accelerating K^+ ions to 10 MeV and including all beam manipulations foreseen in a reactor from injection to final focusing (a recirculator ring is also planned for additional tests). ILSE beams will have the same beam diameter (3.5 cm), the same line charge (0.25 μC/m), and the same emittance (1.0π mm·mrad) as the reactor driver, allowing for studying critical space-charge related aspects.

Bangerter also briefly commented on the problem of the number and the geometry of the converters, which emerged as a central issue at the symposium. Most reactor concepts prefer axial illumination, which also simplifies beam transport and focusing. Within certain limits, target performance increases with intensity and specific energy deposition and again gives preference to less symmetric illumination. On the other hand, the fusion capsule requires symmetric drive. The general problem, which has profound implications for reactor design, emittance level, etc., is the energy penalty associated with the lack of beam spherical symmetry. Currently, U.S. researchers believe the optimal choice is two-sided illumination with the standard parameters quoted above, but in Bangerter's words, "this will stay as an open issue for the next decade."

The ILSE program has received very positive opinions by review commissions but has not yet been funded. In the meantime, component development, system studies, and beam transport simulations have been pursued aggressively.

S. Eylon et al. (LBL) have developed and successfully tested on STBE an alumino-silicate ion source, yielding a current of 95 mA (19 mA/cm^{-2}) K^+ ions, with an emittance of 0.2π mm·mrad, only limited by source diode optics. The high-current injector for ILSE, providing 2 MeV, 800 mA, K^+ ions is under construction (S. Yu et al., LBL and LLNL). Acceleration and focusing occur in a set of electrostatic quadrupole (ESQ) units.

Scaled experiments have been conducted (S. Eylon et al., LBL) to study emittance growth in ESQ by using a K^+ ion source and a quarter-scale setup (when compared with ILSE requirements); in addition, beam transport experiments were performed in a 1-MV electrostatic lens accelerating column. In both cases, the experimental measurements were found in good agreement with the theoretical predictions.

Transverse beam combining has been investigated by two-dimensional particle-in-cell simulations by K. Hahn (LBL). He has studied emittance growth due to the heating caused by space-charge effects and aberrations. Scaled projections show that at the driver level, emittance growth is significant but small enough to be tolerated in a reactor; typically in non-optimized designs, ~7% of the particles are lost.

A full-scale induction module has been built and tested at LBL (L. Reginato), and a number of amorphous magnetic materials have been tested to establish an overall optimum design.

Recirculating Induction Accelerators

A new, 2-yr study of recirculating induction accelerators (or recirculators) as low-cost HIF drivers has recently been completed and was summarized by Barnard (see J. Barnard et al., LLNL and LBL). The goal is cost reduction with respect to single-pass induction linacs. A typical recirculator for a 4-MJ, 10-GeV driver would consist of three rings with the larger having a diameter of ~600 m (to be compared with the 5- to 10-km length of a single-pass linac). The study has determined the major physics and technology issues and estimated the cost of the device to be $500 million and the efficiency to be 35%. The design is based on three elements: induction accelerator modules, dipole bending magnets, and quadrupole focusing magnets. Size reduction is achieved through repeated use of some structures, which deal sequentially with beams of varying energy.

Outstanding engineering issues are then the feasibility of high repetition rate and of high efficiency, pulsed elements, generating variable waveforms. Some of the foregoing requirements have already been demonstrated in scaled tests. L. Reginato and co-workers (LBL) have built a one-quarter-scale ramped dipole; 94% energy efficiency has been demonstrated. M. Newton and H. Kirbie (LLNL) have built a 3-kV, 100-A, MOSFET technology-based module, operating at the needed 100-kHz frequency. ILSE requires a 5-kV, 1-kA modulator, which is currently under construction. (For comparison, a 100-kV modulator is needed for a reactor driver.) Other modulators, with pulse-forming networks, employing a high number of programmable switches, have been designed cooperatively by T. Godlove et al. (FM Technology and G. Mason University, Fairfax).

The key physics issues are the minimization of particle loss due to interaction with background gas, and more demanding emittance and centroid control requirements. These constrain the beam radius to be larger than ~2 cm. Simulation studies show that space-charge related instabilities can be controllable with careful design.

Beam Dynamics in Induction Accelerators

Space-charge-dominated beam transport has been the object of several investigations.

Beam transport in magnetic quadrupoles, such as those foreseen for ILSE, has been studied by code simulations by C. Celata et al. [LBL and U.S. Naval Research Laboratory (NRL)]. In particular, they found that for proper design choices, the ratio a:L (where a is the useful dynamic aperture and L is the half-lattice period) can reach values ~0.2 or even larger [notice that the maximum transportable current scales as $(a/L)^2$].

Friedman et al. (LLNL and NRL), by means of three-dimensional and r-z warped simulations have studied, among the other topics, bent beam dynamics and ESQ injectors for ILSE (contributing to design improvements). They have also addressed the longitudinal instability in driver-scale beams, confirming the theoretical predictions on the growth and damping of forward and backward waves, respectively, and have shown that module capacitance has a major stabilizing effect.

Longitudinal instabilities were reviewed by E. P. Lee (LBL), who described the efforts in progress for ameliorating the instability. He showed that predicted low-frequency growth rates of the longitudinal instability are considerably reduced when the gap capacity is taken into account, and resonant growth is suppressed by low resonance Q-values and dynamical effects. Feedforward control at low frequency is also promising.

A wide-range, scaled-down experimental investigation of this topic has been performed for the past several years on the University of Maryland Electron Beam Transport Facility (M. Reiser et al., J. G. Wang et al., and D. X. Wang et al.). Recently, the effect of localized space perturbations was studied and found in agreement with theory, and bunch compression by time-dependent induction acceleration has been demonstrated.

O. Anderson (LBL) has instead studied the emittance growth of displaced beams, with the goal of determining realistic tolerances for initial beam alignment and matching.

RF Linacs and Storage Rings

I. Hofmann (GSI) reviewed the basic limitations in the RF linac and storage rings approach and discussed several recent developments.

Crucial design limitations studied by the GSI groups concern beam losses in storage rings due to intrabeam scattering, the development of instabilities in coasting and bunching beams, and the final focusing.

Recent computations of beam losses in storage rings have been performed by D. Budicin et al. (GSI and University of Genova), using measured charge-exchange scattering cross sections. It turns out that in typical reactor scenarios, Bi^+ losses are tolerable and independent of the emittance. The case of Au^- (an ion proposed in a scenario involving non-Liouvillian stacking[6]) is different because the losses increase with decreasing the emittance and are only tolerable for emittances larger than 10π mm·mrad.

As far as space-charge-dominated bunched beams are concerned, reactor designs assume that the conventional (Keil-Schnell) threshold current for instability is exceeded by a factor $\alpha = I/I_{th} \approx 10$. This topic is now being studied at the ESR facility. Recently, $\alpha = 0.5$ was measured with a bunch of 3×10^8 Ne^{10+} ions (with energy of 250 MeV/amu). Since the observed α is limited by intrabeam scattering (which grows with Z^2/A), the use of lower charge, heavier ions should allow for reaching the needed value of α.

In another experiment on SIS-ESR, for the first time, fast bunch compression has been achieved (the length of a 250 MeV/amu O^+ bunch has been decreased from 250 to 40 ns).

I. Hofmann also discussed the influence of indirectly driven target parameters on driver design. He considered a conventional concept, consisting of a linac, followed by transfer rings (performing horizontal stacking) and then by storage rings (performing vertical stacking), with in-vacuum ballistic focusing. He assumed the same beam dynamics limitation for all cases, namely, tune shift $\Delta Q = 0.7$ after adiabatic bunching, Keil-Schnell $\alpha = 10$, $\Delta Q = 5$ at fast bunching. He considered the cases of two-converter hohlraums driven by 5-MJ, 500-TW beams of 10-GeV Bi^+ ions, with spot radius $b = 1.3$ mm and $b = 3$ mm, respectively, and a diffuse-converter target (hotraum) with $b = 5$ mm, driven by 10 MJ, 1000 TW of 6-GeV Bi^+ ions.

Of course, driver parameters (emittance, momentum spread, number of rings, and number of beamlets) for the hohlraum with larger spots (3 mm) are considerably relaxed when compared with those for the case with smaller spots (1.3 mm). The comparison between the $b = 3$ mm hohlraum and the hotraum target shows that for the latter, the emittance is somewhat relaxed (by a factor of ~1.7), but the number of beamlets and the percentage of beam holes in the reactor surface grow by factors of ~3 to 4; e.g., the number of beamlets is 240 for the hohlraum and 960 for the hotraum target.

I. Hofmann stressed that the demonstration of the viability of the adopted design constraints is essential: The use of more conservative constraints would increase the number of beamlets and the percentage of beam holes in the reactor surface to unacceptable values unless non-Liouvillian stacking techniques were employed. Should the latter turn out to be necessary, proper consideration should be given to Au^- ions and to using photoassisted stacking from Au^- to Au^+, which sets less demanding requirements to the photon source than the use of Bi^+ ions.[6]

An important development in RF linacs is given by the inter-digital H linac described by U. Ratzinger (GSI). A zero-degree synchronous particle structure and magnetic focusing lenses are combined in such a way that the emittance of each section is well adapted to the acceptance of the following structure. In such a way, particle acceleration close to the crest of the RF wave is possible, and emittance-decreasing effects are kept at low level. In an experiment at GSI, an acceleration potential of 4 MV/m has been measured for beams with charge-to-mass ratio $Z:A \approx 0.1$. Work is in progress to go to the smaller $Z:A$ of interest to HIF.

The status of ion sources and recent work on several types of sources was reviewed by B. Sharkov [Institute of Theoretical and Experimental Physics (ITEP), Moscow]. In particular, he described a CO_2 laser-driven ion source, producing a current density of 4.7 mA/cm^2 of ions in charge state $Z = +30$ and achieving good stability, small momentum spread, and high duration (10^6 shots).

Radio-frequency quadrupoles for the early stages of acceleration are being developed at the University of Frankfurt (see H. Deitinghoff et al. and A. Kipper et al.) and at Tokyo Institute of Technology (see Y. Oguri et al. and M. Okamura et al.). The device built at Frankfurt operates at 27 MHz and accepts in input a 25-mA current of U^{2+}, at 2.2 keV/amu, and accelerates them to 17.6 keV/amu. This RF quadrupole (RFQ) is the prototype of the first part of a larger RFQ (accelerating ions up to 200 keV/amu), which may be installed in the new high-current injector for the GSI accelerator.

Radio-frequency amplificators are also the source of energy of mismatch oscillations leading to emittance growth. R. Müller (GSI) described a theoretical work showing that growth or damping of oscillations depends on the characteristics of the amplifier and feedback loops.

Several other problems in low-energy transport have been studied by German researchers. R. Becker (University of Frankfurt) has studied numerically space-charge compensation of thermal beams and has found a relationship between the amount of compensation of the beam and the temperature of the compensating particles. U. Pozimski et al. and P. Gross et al. (University of Frankfurt) discussed measurements on the influence of partial space-charge neutralization on transverse beam emittance.

An interesting study exploring a method for producing high-efficiency focusing and bending magnets was presented by P. Spiller et al. [Max-Planck Institut für Quantenoptik (MPQ), Garching, GSI, and University of Giessen]. They reported experiments performed at GSI-UNILAC on pulsed, iron free quadrupole and dipole magnets, showing current density enhancement up to a factor of 160.

Beam Dynamics in Storage Rings

The behavior of space-charge-dominated heavy-ion beam bunches in storage rings is one of the single most critical aspects of HIF. Only two papers dealt with this topic, but both presented pioneering, fundamental work.

G. Kalisch and I. Hofmann (GSI) reported the first experiments on bunched beams, performed at the GSI facility. In a series of experiments, the growth of the bunch length of stationary cooled bunched beams was measured. In another series, the first fast compression of an intense (O^+) beam was performed. Excellent agreement with theory and simulation was reported.

D. Möhl (CERN) studied the space-charge induced fast crossing of betatron resonances, which has important repercussions on the feasibility of HIF (it is crucial to the choice of the number of rings and bunches, of the emittance, etc.). Such a process is important in the final stage of bunching, just prior to ejection onto the target. In perspective drivers, large coherent and incoherent tune shifts ΔQ are needed to keep the number of independent storage rings at a practically small value. Scaling from normal high-energy research synchrotrons indicates that very pure quadrupoles and very small field errors are needed to accommodate with incoherent and coherent tune shifts, respectively. In both cases, for typical HIF values ($\Delta Q \approx 1$), tolerances should be about one order of magnitude smaller than typical uncompensated values of the CERN-PS. A possible affordable driver scenario might contemplate working with a large incoherent tune shift ($\Delta Q \leq 5$) during final bunching (occurring on the short time scale of 10 to 50 μs) but keeping the coherent detuning at stacking and bunching (lasting $\sim$ 5 to 50 ms) and the incoherent detuning at stacking small enough (i.e., $\Delta Q \leq 0.5$) to avoid resonances. Good news in this context is provided by an experiment performed on the CERN-PS with 1-GeV protons in which an incoherent tune shift $\Delta Q = 0.8$ was achieved.

Other Topics in Driver Research

An alternate driver concept was proposed by D. Kosharev (ITEP) and further analyzed by A. Barchudaryan et al. (ITEP). In the scheme, called charge symmetrical driver, beam neutralization is accomplished by accelerating positive and negative ions simultaneously. Currents as large as 10 kA per particle specie per transport line can be achieved at zero net current.

Schemes and parameters for intermediate test facilities, capable of focusing on a small converter energy of the order of 100 to 200 kJ, were discussed by R. Arnold and R. Müller (GSI). Basically, the accelerator consists of a linac followed by a 300-Tm synchrotron; 32 beams are focused onto the target. An analog concept was proposed by T. Hattori et al. (Tokyo Institute of Technology).

The scheme for non-Liouvillian stacking of Bi^{++} ions proposed by Rubbia[4] requires a vacuum ultraviolet laser source with a power of the order of 100 kW. G. Dattoli (ENEA) (sec Ciocci et al.) described a design study of a free-electron laser (FEL) operating in the 80-nm wavelength region and with parameters suitable for the foregoing scheme. The FEL is based on an oscillator-amplifier concept. A high-quality 2.5-MeV electron beam drives an FEL oscillating at 240 nm. The beam extracted from this undulator is injected into a second undulator tuned at the third harmonic of the first one. Peak power density in excess of 10^5 MW/cm^2 and average power density larger than 3×10^3 MW/cm^2 are predicted. The design work was also supported by three-dimensional simulations (see A. Di Pace and E. Sabia, ENEA).

FINAL FOCUSING AND REACTOR PROPAGATION

I. Hofmann et al. (GSI and University of Maryland) have theoretically studied the problem of space-charge effects in final focusing of a bundle of beamlets in vacuum (where space charge is fully effective). One of the main results is a significant sensitivity of the axial focus position (and then of the beam size on the target) on beam current. It is found that beam size grows proportionally to (Z^2/A) $(\delta I/I)$ and that the effect depends on the total current in the bundle, not on the number of beamlets. For practical reactor cases, where current pulse shaping implies $\delta I/I \approx 1$, vacuum propagation appears still feasible for 10-GeV singly charged Bismuth ions and for sufficiently large spot size ($b \approx 3$ mm), but not for smaller spots, lower ion energy, or higher charge state. Improved focusing might be achieved by using appropriate nonuniform beamlet configurations or a larger number of bundles than converters and/or (a technically difficult task) by pulsing the matrix focusing lens. Alternatively, charge-neutralized modes of beam propagation have to be considered.

Charge neutralization of heavy-ion beams in a reactor chamber with ion density $n = 10^{12}$ to 10^{13} cm^{-3} was discussed by B. Langdon (LLNL). Possible solutions include beam neutralization by electron pickup from preformed plasmas and partial neutralization by electrons produced by collisional ionization of the chamber vapor. C. Olson et al. [Sandia National Laboratories (SNL) and NRL] have instead studied the problem of gas breakdown for ballistic transport in plasmas, in the 0.1- to 10-Torr gas pressure region. In an experiment performed on the GAMBLE II accelerator at NRL (with 1-MeV H^+ beams, 1 kA/cm^2 current density, and diameter $D = 1.5$ cm), a good neutralization (total net current 2 to 8% at radius $r \approx 4$ cm) has been measured for propagation in a gas at pressure $p \approx 0.25$ to 0.4 atm. Extrapolation to HIF indicates that ballistic transport (with net current <1%) should be possible for $p \geq 1$ Torr.

Focusing techniques based on plasma lenses have been investigated at GSI (in cooperation with several German institutions). Emphasis is currently on lens optimization, which is achieved by tapering the lens in such a way as to fit the lens shape to the beam envelope (thus increasing the field gradient in the direction of the beam motion) (M. De Magistris et al., A. Tauschwitz et al., and M. Stetter et al.). Parameters have to be chosen in such a way that the skin depth is larger than the tube diameter. One prototype of such a so-called wall-stabilized plasma lens driven by a 22-kA current has been able to focus beams of 11.4 MeV/amu nickel ions with 1.6-Tm rigidity and diameter $D = 1$ cm (produced by UNILAC) onto a $D = 300$-μm focal spot. A somewhat smaller focus is expected on SIS, leading to an on-target intensity increase larger than one order of magnitude than achieved with conventional quadrupoles.

BEAM/PLASMA INTERACTION

As reported by D. Hoffmann (GSI), the GSI facility now allows for stopping-power measurements on all ions in the energy range from 45 keV/amu to 1 GeV/amu. First experiments on plasmas (already reported at the previous symposium) showed enhanced stopping power and increased effectiveness in charge state in a plasma (when compared with the corresponding values in a solid medium) and confirmed recent, advanced theoretical model predictions. Although under typical HIF conditions, in the best converter materials range shortening is small, details of the interaction may be of great interest, and a large density-temperature domain is still awaiting for experimental measurements. Recent experiments have studied the stopping power in the ion energy region ($\approx$50 to 100 keV/amu), where the greatest difference between cold stopping power and plasma stopping is expected. A stopping-power increase by a factor 30 has been measured between cold gas and a plasma with $n_e \approx 10^{17}$ cm^{-3} and $T_e \approx 10$ eV, in agreement with theory. Such measurements have been made possible by the development of accurate X-ray and optical diagnostics, discussed in papers by W. Laux et al. and H. Wetzler et al., respectively. A collaboration between French groups [Laboratoire de Physique des Gaz et des Plasmas (LPGP), Orsay; GREMI, Orleans; and GPS, Paris VI] is interested in the accurate study of the stopping power (and hence of the ion charge) in the energy region $\approx$ 5 MeV/amu, where the stopping power is close to a maximum. They have developed a new theoretical approximation, called average correlated hydrogenic atom model (ACHAM), which is valid also at lower density than the usual average atom approximation and includes the effects of dielectronic ionization and of autoionization (G. Maynard et al.). When using hydrogen targets, particular care is needed in evaluating the stopping effect of high-Z impurities. Gardes et al. have developed a new method for diagnosing low-concentration impurities, in which a Cl^+ ion beam is used as a probe. Comparison between experiments and ACHAM shows that no simple additivity rule can be used for the stopping power in the low-density ($n_e \approx 10^{17}$ cm^{-3}) region.

Plans for an experiment to be performed at Instituto Nationale di Fisica Nucleare (INFN)-Laboratori Nazionali Legnaro for studying the stopping of heavy ions in a dense, hot plasma (with $n_e \leq 10^{21}$ cm^{-3} and $T_e \approx 100$ eV) were presented in a poster by Pusterla [see Deutsch et al., LPGP; Consiglio Nazionale delle Ricerche (CNR), Padova; and INFN, Padova]. Heavy ions accelerated by a tandem and by the linac ALPI up to 10 MeV/amu will be focused onto a plasma produced by a Q-switched neodymium laser.

Work on stopping-power theory concentrated on heavy-ion pair effects, on ion-linear potential wake effects (J. D'Avanzo et al., CNR, Milano), and on the calculation of the stopping power in strongly coupled plasmas (G. Zwicknagel et al.).

Singly ionized clusters of N atoms (with $N \approx 50$ to 100) can be considered as very heavy ions, and their application to fusion was suggested by C. Deutsch (LPGP). At the symposium, he described models for cluster fragmentation from Coulomb explosion and showed computations of the correlated stopping of N ions falling close to the initial projectile trajectory. Estimates indicate that 300 keV/amu clusters are needed for indirect-drive inertial fusion application. Of course, prerequisites for any ICF program are the nondestructive acceleration of the clusters and improved studies of fragmentation and stopping. As far as the latter topic is concerned, E. Nardi and Z. Zinamon (Weizmann Institute of Science, Israel) have performed molecular dynamics simulation of C_{64} clusters in a plasma; they have showed, in particular, that breakup is sensitive to the interparticle interaction.

TARGET STUDIES

Target problems were discussed in 2 review papers (by J. Lindl and by S. Atzeni), in 4 invited talks, and in about 20 contributions.

J. Lindl (LLNL) described how the experiments conducted within the laser-driven ICF program provide a solid base for calculating HIF hohlraums. S. Atzeni (ENEA) summarized recent advances on a few key issues for target design.

A great deal of effort has been devoted in the past 2 yr to quantitative studies of radiation generation and symmetrization and of hydrodynamic instabilities. In addition, several authors (from Germany, Italy, and Russia) have studied a new type of radiation-driven target, in which the converter is diffused in the form of a low-density, thick spherical shell, contained in the radiation-confining casing, and, in turn, enclosing the fusion capsule. Such studies, promoted by a suggestion by Rubbia (see Ref. 7) have also stimulated the accelerator community to study the influence of several target configurations on driver design (see, e.g., the foregoing discussions of Rubbia's and Hofmann's papers).

In his talk, Atzeni showed that target gain estimates depend critically on assumptions concerning beam-to-capsule energy coupling and concerning survivability to hydrodynamics instabilities. Crucial physics issues for target design are therefore radiation generation and symmetrization without excessive coupling degradation and the understanding of the Rayleigh-Taylor instabilities. Robustness to instabilities during inward acceleration limits the target in-flight-aspect ratio IFAR to values of ~25, requires avoiding internal structures (e.g., high-density pushers), and requires good surface finishing (even for radiation drive). Ignition robustness is increased by minimizing the interval between the start of stagnation and ignition. Good pulse shaping is essential for satisfying this latter requirement and for producing the necessary spatial entropy shaping without using high-density pushers.

Efficient radiation conversion requires deposited powers of the order of or larger than 10^{16} W/g. Analytical studies and two-dimensional simulations by Atzeni and by Ho and Lindl (LLNL) demonstrated that intermediate-Z materials (such as aluminum) or low-Z materials, doped with some amount of high-Z atoms (in such a way as to make the converter marginally optically thick) are the best converter materials for reactor-size conditions. Note that for such materials, range shortening due to plasma effects is negligible. Lindl showed for the first time several converter configurations envisioned by the LLNL researchers.

Radiation symmetrization is a rather controversial topic. Researchers in the United States believe that suitable hohlraums with two ion beam heated converters can drive the fusion capsule with the symmetry required for attaining ignition at moderate input energy (see below). Their forecasts are supported by their capability of accurately modeling current laser-driven hohlraum experiments. In the past 2 yr, a few European and Japanese groups have addressed this topic by means of simple static models and/or by semianalytic models. They all concluded that when simple cylindrical converters, emitting radiation from their lateral surface are considered, two-converter hohlraums do not allow for achieving the required symmetry, while six converters might be adequate (M. Temporal and S. Atzeni, INFN and ENEA). Introduction of shields or changes in the hohlraum design might, however, lead to improvements. Analogous conclusions have been drawn by Osaka scientists (the work of M. Murakami, reported by K. Nishihara) and by Frankfurt researchers (K. Kang et al.), who also pointed out the need for self-consistent treatments of radiation hydrodynamics in the hohlraum.

In this context, R. Ramis and J. Meyer-ter-Vehn (Polytechnic of Madrid and MPQ) reported that they have developed a new two-dimensional hydrocode (named MULTI-2D), including an original treatment of multigroup, multiangle radiative transfer.

Lindl (LLNL) outlined the experimental activities being performed at LLNL. The hohlraum laser plasma physics program has the objective of demonstrating symmetry control, with the pulse shaping and the internal hohlraum structure scaled from the hohlraum required for ignition on the National Ignition Facility. Reproducibility of the implosion symmetry and control of the time-averaged P_2 nonuniformity mode at 1% level (rms) have been demonstrated. The ability to model the time-dependent evolution of the capsule has also been verified.

Experiments on single- and multimode Rayleigh-Taylor instability have shown a close correspondence between theory (or simulation) and experiments over a wide range of parameters. Partial ablation stabilization has been demonstrated, in agreement with the so-called Takabe's formula.[8] Application of these results to ICF targets predicts safe implosion of targets with IFAR $\approx$ 30 and with surface finish of 500 to 1000 Å.

The foregoing results have been used as input to estimates of the target gain and of the energy threshold for ignition. For centrally igniting targets, it is found that the ignition energy scales as $v_i^{-5}\beta^4\eta_c^{-1}\eta_h^{-1}$, where v_i is the implosion velocity, β is the isentrope parameter, and η_c and η_h are, respectively, the coupling efficiency and the hydrodynamic efficiency. For velocities $v_i \approx 3.5 \times 10^7$ cm/s and values of β, η_c, and η_h considered achievable in indirect drive laser ICF, the driver energy threshold for ignition lies around $E = 1$ MJ. In the moderate-to-high gain region, the gain increases with decreasing implosion velocity, and the envelope of the gain curves for different velocities and given coupling efficiency scales as $G \propto E^{0.7}$.

In the case of HIF, η_c depends on the conversion efficiency, which is an increasing function of the specific power delivered to the converters. The really critical, specific issue for HIF is, thus, the achievement of the brightness required for the intensity and energy deposition needed for efficient conversion of beam energy into X rays. The more recent LLNL studies predict that gains of interest to IFE (i.e., $G \approx$ 50) are obtained by delivering 2.5 MJ of 6-GeV heavy ions (with $A \approx 200$) on a 2-mm-(radius) spot or 5 MJ of 10-GeV heavy ions (with $A \approx 200$) on a 3-mm spot.

J. Meyer-ter-Vehn (MPQ) showed that the aforementioned ignition threshold scaling can be interpreted within the isobaric model by following an approach already discussed at the Monterey Symposium by Atzeni.[9] Indeed the LLNL gain gurves (generated for fixed implosion symmetry and stability constraints) can be nearly quantitatively reproduced by assuming a given ignition condition and constant fuel compression. At least in a certain region of parameters, the model predicts an ignition energy threshold scaling proportionally to $v_i^{-4.5}\beta^3$.

A. R. Piriz and J. G. Wouchuk (ENEA) instead developed a somewhat more sophisticated model in which the fuel profiles at ignition are calculated consistently with the implosion phase. Good agreement with the LLNL predictions is found together with a physically plausible interpretation of the ignition cliff.

Meyer-ter-Vehn also briefly discussed the physics of the hotraum targets. In these targets, the radiation generated in the absorber region propagates supersonically in the hotraum itself and drives the implosion of the fusion capsule. Supersonic propagation, which is achieved only for suitably chosen parameters, ensures the hydrodynamic insulation between the ion deposition region and the imploding capsule. Studying this target concept had been suggested by Rubbia[7] and M. Basko and J. Meyer-ter-Vehn have recently published a first target design.[10] It turns out that good energy coupling can be achieved by using heavy ions with energies of 6 to 8 GeV, while the constraint of hydrodynamic insulation makes it necessary to use high beam power and does not allow for low-power prepulses, nor for wide range pulse shaping. In their design, the compression needed for ignition is achieved by using high-density pushers surrounding the fuel. In a safer design, presented by A. R. Piriz and S. Atzeni (ENEA), the violently unstable pusher is not included, but this requires for a given fuel mass a somewhat larger beam energy and a considerably higher pulse peak power. Typically, in these more robust designs, gains of ~30 are achieved by targets driven by ~12-MJ, 8-GeV ion beams. In two related papers, Yu. Romanov and V. Vatulin et al. [Russian Federal Nuclear Center, Institute of Experimental Physics (VNIIEF), Arzamas, Russia] studied by two-dimensional simulations the effect of implosion asymmetries on target gain and suggested that their effects should be contrasted by increasing the beam energy for a given fuel mass. All these results on the hotraums are of a preliminary nature. However, they indicate that alternatives to conventional designs might exist and have had the merit of stimulating considerable debate at the symposium.

Mixing caused by the multimode two-dimensional Rayleigh-Taylor instability was discussed in a poster by S. Atzeni and A. Guerrieri (ENEA), who showed that the usual scaling of the size of the mixing layer, based on similarity arguments, should only be taken in practice as a lower bound. J. G. Wouchuk (ENEA) presented an analytical mode for the mixing stage leading to analogous conclusions. In this context, it should be reported that Yu. Romanov (VNIIEF) pointed out that in some cases, the three-dimensional mixing is substantially different from (and worse than) the two-dimensional phenomenon and argued that this effect added to larger scale asymmetries may raise the ignition energy threshold to values higher than usually assumed.

Target studies based on one-dimensional simulations were presented by J. M. Martinez-Val et al. (Instituto De Fusion Nuclear Escuela Tecnica Superior Ingenieros Industriales, Madrid) and by N. Tahir et al. (GSI). The former authors addressed in particular the problem of volume ignition, while the latter analyzed a certain radiation-driven target.

T. Tlutsy et al. (Weizmann Institute of Science) presented an analytical model for the evolution of ion-beam heated matter in planar geometry.

Accurate opacities are an important ingredient for the interpretation of experiments and for reliable simulations. Advances in this area were presented by A. Rickert and J. Meyer-ter-Vehn (MPQ) who have developed a model taking into account l-splitting and relativistic effects, and by T. Blenski and S. Morel (Ecole Polytechnic Federale de Lausanne, Lausanne).

Advanced fuels might overcome the problems related to tritium breeding and handling and/or to neutron-induced material damage. Three papers, although not specific to HIF, have addressed the conditions for tritium-less fuel burning. D. Churazov et al. (ITEP) and J. Linhart (University of Ferrara) studied the case of deuterium burning in magnetically insulated cylindrical channels. A. Ruggiero (Brookhaven National Laboratory, Brookhaven) proposed a colliding beam method for burning p-^{11}B fuels. The use of the so-called crystalline beams could lead to turning off particle interactions in the individual beams.

LASER AND LIGHT-ION FUSION

In addition to Lindl's talk, three other invited talks described recent results on ICF by laser and light-ion beams.

Nishihara (Institute of Laser Engineering, Osaka) reviewed his laboratory's laser fusion program with emphasis on topics of relevance to HIF. The improvement of the implosion quality (as measured by core symmetry, neutron yield, etc.) with improved beam quality has been demonstrated. Experiments on the Rayleigh-Taylor instability have shown agreement with Takabe's formula[8] in the case of acceleration of pre-perturbed targets, while have shown no growth in the case of smooth targets. A significant technical advance is the development of shell targets made of a liquid fuel saturated cryogenic foam. Foams with densities of 100 mg/cm^3 and cell sizes of 2 μm have been produced.

Light-ion fusion has entered the domain of ICF relevant target experiments. D. Cook (SNL) reported that as a result of a series of technical improvements, the accelerator PFBA II is now capable of delivering on target 180 kJ of 9-MeV lithium ions in a pulse of 30 ns (full-width at half-maximum), with an intensity of 2 to 3 TW/cm^2 and specific deposition power of 1400 TW/g. In experiments with cylindrical targets, consisting of a foam-filled casing, radiation temperatures $T \approx 30$ eV have been measured in the foam. The observed ion stopping, matter heating, radiation generation, and the tamping effect of the foam agree with the theoretical predictions. These results are of great relevance to the diffuse converter targets (hotraums) for HIF discussed earlier.

K. Baumung (Kernforschungszentrum Karlsruhe) described foil acceleration experiments performed with the KALIF facility. This device delivers ~40 kJ of 1.8-MeV protons, with intensity of 1 TW/cm^2 and specific deposition power of 100 TW/g. Pressures in the beam heated matter up to 0.7 Mbar have been measured.

REACTOR STUDIES

W. Hogan presented a paper by W. Meier [W. J. Schafer Associates (WJSA)] and L. Waganer (McDonnell Douglas), summarizing two recent heavy-ion reactor studies sponsored by the DOE. The WJSA and the McDonnell Douglas teams have designed two 1000 MW(electric) reactors, based on induction linac drivers, called Osiris and Prometeus-H, respectively. Both drivers deliver ~ 5 to 7-MJ pulses and 4-GeV ions and operate at 3 to 4 Hz; they have efficiencies to 28 and 21%, respectively. Target gains are ~90 to 100.

Both reactors employ a wetted wall chamber, low-activation structural materials, and means to make the neutron load on structures small, Consequently, both plants can be classified as "totally passively safe" according to the Senior Committee on Environmental, Safety, and Economic Aspects of Magnetic Fusion Energy (ESECOM) classification of the level of safety assurance, and all reactor component quality for class A shallow burial.

Osiris is based on a conservative induction linac design. A porous carbon/carbon (C/C) fabric is used to contain the molten salt Flibe, used as coolant and breeder. The vessel structure is a C/C composite. Prometheus employs a recirculator. The reactor chamber has a lead cooled porous silicon carbide (SiC) first wall and a helium-cooled LiO_2 breeding blanket. The structural material is SiC.

Economic estimates have, of course, a purely indicative nature. It should, however, be observed that the cost of electrical energy is estimated to be slightly lower than that resulting from analogous tokamak studies (ARIES design). This results from a smaller cost of the ICF reactor chamber and a driver direct cost only slightly larger than that of tokamak magnet and heating systems.

W. Hogan (LLNL) also discussed a low-cost strategy for several phases of development of HIF, from an intermediate facility (delivering an energy $E \approx 200$ kJ) to the reactor driver ($E \approx 4$ MJ), based on upgradable linacs and scaled reactor chambers. Prerequisites to this project are the demonstration of ignition on NIF (under conditions relevant to HIF targets) and the demonstration of technical solutions to some technological issues, such as cheap target fabrication, target delivery, and final focusing in the chamber environment.

CONCLUSIONS

R. Bock (GSI) concluded the symposium with a few critical remarks on the present status of HIF research.

In his opinion, the papers presented at the symposium evidenced a perfect sharing of work on drivers between the United States and the other countries, pursuing, respectively, the induction linac and the RF and storage rings approaches. Good contacts between the two communities allow for effective exchange of relevant information. Highlights of induction linac research include the progress in recirculators, innovative component developments, and advanced beam dynamics simulations. Regarding the complementary RF linac and storage rings approach, notable results are the first investigations of beam dynamics driver-relevant issues on SIS-ESR (with the achievement of fast bunch compression), the measurement of a high transverse incoherent tune shift ($\Delta Q = 0.8$) on the CERN-PS, and innovative developments of components, such as the inter-digital H linac structure, the progress on RFQ's and on injectors.

The results of light-ion-target experiments are also important for heavy-ion research because they allow the study of ion-driven target-radiation-physics (heavy-ion beams available for the next several years can only reach specific heavy power two orders of magnitude smaller).

As far as target physics is concerned, the symmetrization problem and the beam-target interface emerge as the critical issues. In addition to a series of European and Japanese studies, a contribution to the former topic has come from the disclosure of important results on radiation conversion and symmetrization obtained in the United States. Still, classification hinders international cooperation.

System studies have been helpful in identifying critical areas on which more work is needed and have confirmed the high expectancies on inertial fusion by heavy-ion beams. Such appealing technical features have attracted the interest of many young scientists as well as of scientists from institutions with significant expertise in HIF crucial fields (in particular, from CERN for the driver and from VNIIEF, Arzamas for the target).

Perspectives are somehow contradictory. In the United States, despite the mentioned great advancements and very positive reviews, the ILSE program will not be funded before 1995. Component development and theoretical and system study will, however, be pursued intensively; also, significant target results are expected from the laser fusion and the light-ion beam program. In Germany, the GSI facility, SIS-ESR, is now fully operational and available for beam dynamics experiments and for the first high-intensity beam-plasma experiments. A significantly large facility is, however, needed for a demonstration of all beam manipulations required in a driver, and for beam-target experiments in the so-called "radiation-physics domain." R. Bock informed the attendees that after a few workshops hosted by the Italian Physical Society and a series of meetings and working sessions organized by C. Rubbia, representatives of some European institutions (from Germany, Italy, Switzerland, Spain, France, and the United Kingdom) met several times during the past few months just to promote a next-step HIF initiative. The participating laboratories intend to form an international working group, having the mission of producing on a time scale of 2 to 3 yr, the project for a European HIF facility (with scope and parameters to be defined by the working group itself after a preliminary assessment).

The next symposium on Heavy Ion Fusion is scheduled to take place in the United States in Fall 1995.

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