conditions. He noted that the present seminar is unique in providing such a wide coverage of presentations, including drivers, diagnostics, laser/plasma interactions, implosion physics (including important new developments in volume ignition using stagnation-free implosions), target manufacturing (including the application of lithographic technology to target manufacture), and plasma generation (including spectroscopy and high-power switching). Yamanaka also briefly commented on the history of this seminar series, noting that the 1972 meeting was important for first bringing U.S. ICF technology to Japan, the 1976 meeting was highlighted by reports of new major laser facilities, and 1982 showed the increasing interest in the area with a record 66 attendees, while the present meeting stresses ICF spin-off areas. He expressed concern about the decision by the U.S. Department of Energy to restrict attendance due to classification issues. He questioned this restriction being placed on a bilateral meeting while full participation is apparently encouraged in international meetings. As a result, he noted that the presentations by "Third World" representatives were even more important to the present meeting than in the past.

Finally, C. Yamanaka compared ICF and magnetic confinement fusion relative to international collaboration. Magnetic fusion energy (MFE), with Joint European Torus, International Thermonuclear Experimental Reactor, etc., has a close collaboration while ICF appears fragmented. He called for increased collaboration in ICF in the interest of mutual benefit, not only for fusion scientists, but for future generations who will need fusion energy.

A. Guenther agreed with C. Yamanaka about the unfortunate limitations put on U.S. attendance at this seminar. He too acknowledged the important contributions by Third World participants. In comments about the presentations, he also stressed the importance of spin-off areas. For example, developments in switching technology and the increased understanding of damage effects in optics should impact future science and medicine. Also, X-ray lasers represent a most important new radiation source, which will strongly influence future science. He noted that the important advances in optical coating technology reported by Japanese researchers will provide an important complement to U.S. work in this area. He concluded by citing energy production and X-ray lasers as the focal points for this seminar series.

H. Takuma concentrated his remarks on the development of the KrF laser as an alternate ICF driver. Advantages of KrF include its advanced state of development. It is scalable to high powers with an amplified spontaneous emission limit of 500 kJ in microsecond operation. A high efficiency is possible (~10% overall) along with a relatively uniform transverse power density, a high repetition rate (~1 Hz), pulse compression and shaping, and compatible optics. A peak energy of 600 kJ in a single beam is predicted. Takuma also cited the advanced semiconductor solid-state laser as a driver candidate with high efficiency, low heat load, and long life. However, the high cost of components and the intensity dependence of the refractive index remain as key development issues. He also suggested exploration of the FEL is warranted, but its potential of achieving the high pulse power required for ICF remains uncertain.

M. Prelas reported on the results from a written survey of opinions on driver issues, which indicated a strong leaning toward diode-pumped solid-state systems and KrF. He suggested that ICF has a stronger chance for commercial power development than MFE because, as shown by this seminar, ICF has remained open to new ideas. He too stressed the importance of developing a "brand X" laser for the driver for a commercial power plant and pointed to the nuclear-pumped laser as one possibility. He also predicted a coming scientific revolution in chemical kinetic studies, biological systems, etc., that would be initiated as the results of spin-offs from ICF technology.

K. Niu also focused his remarks on the development of new lasers as the future ICF driver. He cited excimers, X-ray lasers, gamma-ray lasers, and FELs. In addition to laser issues, he outlined advances and remaining issues in diagnostics, target compression physics, and optics damage. He also stressed the importance of international cooperation in ICF development, especially in view of the large costs associated with advanced facilities. Niu concluded with an observation about economic issues for fusion energy from ICF. The income from a 1-GW(electric) plant is about $20 billion. Costs for a fission plant are about $2 billion and for a fast breeder about $6 billion. The key question is the cost for a fusion plant. Among the many issues that will influence costs are the ability to ignite a burn with minimum energy expenditure and the development of cheap manufacturing techniques for ICF targets.

Following these remarks by the panel members, the discussion was opened to input from other participants, and a lively interchange occurred. S. Nakai closed the discussion by reviewing the remarkable progress made in ICF research and stressed that we are now ready to demonstrate ignition. The achievement of reactor operation, however, will require a large step in laser development from the present 100 kJ/pulse to the megajoule level and ultimately to high repetition rates corresponding to megawatt-level operation. He stated that fusion research is vital to the ultimate existence of mankind.

G. Miley closed the meeting by thanking the participants for their strong input, which made this fourth U.S.-Japan seminar on dense plasmas so successful.

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SUMMARY OF THE U.S.-JAPAN WORKSHOP ON D-^{3}He FIELD-REVERSED CONFIGURATIONS, URBANA-CHAMPAIGN, ILLINOIS, OCTOBER 5-8, 1988

The objective of this workshop was to plan for a proposed D-^{3}He field-reversed configuration (FRC) reactor design study. A review of the status of the physics data base and the identification of critical issues involved in a design study were the main topics of discussion. Also, preliminary organizational plans for undertaking the design study were developed. Planning will be completed at a workshop tentatively scheduled for March 1989 in Japan and workshops to initiate the design effort itself are proposed for the 1989–1990 exchange period.

Japanese participants in this workshop included H. Momota (Nagoya University), A. Ishida (Niigata University), S. Ohi (Osaka University), M. Ohnishi (Kyoto University), and Y. Tomita (Nagoya University).

U.S. participants were W.-H. Choe (University of Illinois), J. Eddleman (Lawrence Livermore National Laboratory), R. Krakowski [Los Alamos National Laboratory (LANL)], R. Lovelace (Cornell University), B. Maglich (United Sciences, Inc.), G. Miley (University of Illinois), J. Santarius (University of Wisconsin), C. Singer (University of Illinois), L. Steinhauer (Spectra Tech., Inc.), M. Tuszewski (LANL), and B. Wright (LANL).

Several observers also attended: M. Heindler and W. Kernbichler (Graz University of Technology, Austria) and O. Agren (Uppsala University, Sweden).

G. Miley and H. Momota served as coordinators of this workshop.

G. Miley reviewed discussions at earlier related workshops ("Advanced Fuels in a FRC," held in Nagoya, Japan, in June 1986, and "Large Gyroradius Equilibrium and Stability Theory," held in Niigata, Japan, in September 1987). H. Momota explained the reasons for using D-^{3}He fuels in an FRC and discussed objectives for a reactor study. Significant advantages of D-^{3}He include elimination of neutron damage to materials, reduced radioactivity involvement, elimination of tritium breeding, and improved energy conversion efficiencies. L. Steinhauer and M. Tuszewski summarized key issues relative to D-^{3}He FRC reactors. These include stability restrictions due to S limitations, the need and techniques for a deuterium-tritium (D-T) start-up, and options for minimizing anomalous transport. The need for an optimized start-up source was also noted. The parametric range available for D-^{3}He operation was summarized by W. Kernbichler.

Past FRC reactor studies were reviewed by R. Krakowski and G. Miley. The *in situ* D-^{3}He concept SAFFIRE was covered by Miley, who stressed issues related to steady-state current drive and compatibility with a cold plasma blanket on open field lines. In contrast, the compact torus fusion reactor (CTOR) D-T reactor study covered by Krakowski used a translating plasmoid burn chamber approach. One issue discussed was whether or not the D-T portion of the translating burn could be held to a sufficiently small fraction of the burn time to make this approach attractive for D-^{3}He operation. An efficient formation technique is also an essential element for this approach due to its pulsed operation.

Further insight into the physics of the transition from D-T to D-^{3}He burn was provided by M. Ohnishi. His technique involves the control of the external magnetic field, refueling, and the internal flux supply to achieve the desired temperature trajectory. The physics of the initial evolution of the D-T plasma to ignition was described by Y. Tomita. He also proposed the possibility of using a field-reversed theta pinch for the formation stage. His analysis indicates that adequate temperatures can be obtained even with present limitations on the theta pinch coil voltage.

Direct energy conversion, an essential element of a D-^{3}He FRC, was discussed by J. Santarius. Possible approaches include electrostatic particle collection, synchrotron radiation conversion, and compression/decompression cycles. Achievement of a narrow energy distribution of escaping ions is essential for effective electrostatic collection. The ability to incorporate the other techniques into a suitable configuration requires more study.

Presentations by A. Ishida, R. Lovelace, W.-H. Choe, and M. Ohnishi reviewed a variety of stability issues. Energetic particle beams are potentially attractive for suppression of the rigid external tilt of the FRC plasma. However, the internal tilt is more serious since it cannot be stabilized by external fields and could cause rapid destruction of the configuration. (However, when kinetic effects are taken into account, it is not clear that the tilt has occurred in all "well-confined" FRC experiments thus far.) Theory and experimental results may not be consistent in this area. Several aspects of plasma rotation were also discussed. Ohnishi analyzed rotations driven by anisotropic leakage of energetic proton fusion products and found this effect to be manageable.

Transport scaling is a crucial topic for the proposed reactor study. S. Ohi described the use of a one-dimensional magnetohydrodynamic simulation code to study particle and trapped flux decay in an FRC. Results are consistent with zero-dimensional transport analysis, and the analysis is being extended to a lower hybrid drift resistivity case. A discussion of the scaling to use in the reactor study ensued. Opposite extremes are a Bohm-like transport and the loss sphere scattering model. A tentative conclusion was to employ a loss sphere form with reduced absolute magnitude.

In addition to FRCs, several other related configurations were discussed including the Migma, Extrap, and Race (by B. Maglich, O. Agren, and J. Eddleman, respectively). The Migma shares some stability issues with the FRC so advances in its understanding are of interest, including the recent development of a strong focusing field configuration. There was some discussion of the possibility of using the Extrap as a formation technique for the FRC. Race poses an intriguing concept for compression heating by acceleration in a converging magnetic (conical) field.

The final session involved three panel discussions:

1. physics issues (cochairs: A. Ishida and L. Steinhauer)
2. reactor issues (cochairs: M. Ohnishi and R. Krakowski)
3. summary and future directions (cochairs: H. Momota and G. Miley).

While a number of key issues were identified for further study, there was general agreement that a sufficient data base exists to carry out a meaningful reactor study at this time. Such a study is needed to illustrate the potential attractiveness of a D-^{3}He FRC plant and provide guidance for experiments and a development strategy.

Finally, H. Momota presented a possible matrix for the reactor study tasks. It included consideration of heating, refluxing, refueling, B control, rotational control, stability (internal, external tilt, rotation), and plasma parameters (n, T, l, S, etc.) through the operational phases of formation, heating, D-T ignition, D-T burn, D-^{3}He ignition, and D-^{3}He burn. Refinement of this matrix will be an action item for the next workshop.

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