the 2- to 100-μs range. T. Tanabe (Osaka University) reported that the fluorescence in silica is a broad peak centered at 800 nm. W. Unruh (LANL) and D. Griscom (NRL) reported on spallation neutron irradiation of pure and OH-doped fiber optics at much higher fluence than has previously been investigated. With increasing irradiation, the absorption increases first in the ultraviolet range (200 nm) and then progresses to longer wavelengths. At very high dose, there was some indication that the absorption decreases in the 200-nm range. There was speculation that the fluoride-doped fiber cladding might be more resistant to the radiation than the core. K. Noda (JAERI) compared the efficiency of generating degradation in optical fibers and found that neutron irradiation is more efficient in inducing absorption than gamma irradiation.

K. Abe (Tohoku University) reported on postirradiation examination of metal-ceramic joints. Thermal expansion coefficient matching is important. One joint of alumina and vanadium alloy survived 60 dpa of fast reactor irradiation.

T. Tanabe (Osaka University) irradiated diagnostic instruments and components with 14-MeV neutron irradiation. He reported that a charge-coupled device camera failed at 2×10^{10} n/cm^2. An irradiated electron multiplier tube produced pulses from the neutrons similar to those from electrons. Tanabe also reported that 14-MeV neutrons are ~100 times more damaging to pulse-counting detectors than an equal absorbed dose of fission neutrons.

Radiation sources suitable for dynamic measurements in both the United States and Japan were discussed. The following were of particular interest:

1. a temperature-controlled materials irradiation facility at Japan's Joyo fast reactor that will be available in 1997
2. a cryogenic facility that is proposed for development at the OKTAVIAN 14-MeV neutron source
3. a proposed upgraded LASREF
4. an instrumented irradiation facility being built at the High-Flux Isotope Reactor (HFIR) that is expected to be operational by the end of 1993.

The sources considered most suitable for future *in situ* experiments are the LASREF spallation radiation source at the Los Alamos Meson Physics Facility at LANL, the Japanese Material Testing Reactor at Oarai, the HFIR at ORNL, and the OKTAVIAN 14-MeV neutron source at Osaka University.

A copy of the proceedings, which includes a summary and presentation viewgraphs, can be obtained from the author.

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SUMMARY OF 7TH U.S.-JAPAN D-^{3}He WORKSHOP, CHAMPAIGN, ILLINOIS, MARCH 16-18, 1993

INTRODUCTION

G. Miley (University of Illinois) hosted this meeting of the U.S.-Japan working group devoted to the physics and application of D-^{3}He for the creation of fusion energy. The 3-day meeting was held at the University of Illinois to discuss the latest analyses, experiments, and applications of advanced fuels and included a tour of the Fusion Studies Laboratory.

SESSION I: L. STEINHAUER

D-^{3}He Tokamak Reactor with Alternating Current Operation

O. Mitarai discussed the use of an inductive alternating current (ac) using D-^{3}He to operate a tokamak reactor to eliminate problems encountered from steady-state operation. The reactor analyzed had a 9.5-m major axis and 2.8-m minor axis and operated at 10 T and a plasma current of 53.6 MA. It was analyzed to operate successfully in the first-stability range using a small current power drive of ~50 kW.

The underlying physics assumptions were first-stability operation with high triangularity and four times L-mode confinement. Fairly aggressive technology assumptions were made, including rectenna conversion of synchrotron radiation energy and a relatively high maximum field of 18 T in the ohmic transformer. Given these conditions, a large auxiliary heating power of nearly 500 MW would be needed during startup. Several ideas were mentioned that might reduce this requirement, including "hot-ion" operations (ion temperature 1.5 to 2 times the electron temperature) or spin polarization of the fields. While some work has been done on spin polarization, no approach is known to achieve hot-ion operation.

Overview of Inertial Electrostatic Confinement and Possible Use for Burning D-^{3}He

G. Miley discussed the origin of inertial electrostatic confinement (IEC), another potential confinement approach for advanced fuels. The operational principles of IEC were described. Ions and electrons are injected into a spherical shell configuration that is designed to trap ions in a potential well to produce high reaction rates in a small core, providing a high-beta confinement approach. The IEC does not require magnets: The combination of the well potential and the inertia of the ions provides the necessary confinement. Beam-beam reactions make IEC well suited for burning D-^{3}He. The experimental studies being conducted at the University of Illinois were described. Neutron production has been achieved, creating interest in IEC as a neutron source. D-^{3}He experiments are planned next. The ultimate goal is a reactor.

Physical Issues in the Design of a D-^{3}He Tokamak Reactor

S. Tanaka discussed the results of a study to consider the feasibility of steady-state burning of D-^{3}He in a tokamak. The analysis is based on confinement in the second-stability regime and a double-null divertor. The conclusions reached were that the tokamak is not suited to burning D-^{3}He, direct conversion from synchrotron radiation is not a candidate, and a first-wall design using water coolant from burning D-^{3}He works well.

Somewhat more conservative technology assumptions were made in this design than in that by Mitarai, specifically, conventional thermal and reasonable wall reflectivity of synchrotron radiation. The more conservative assumptions necessitated the second-stability regime. The assumption of low recycling, which was considered a realistic physics assumption, led to a large requirement on the divertor region volume to handle the heat removal. The conclusion was that a tokamak with realistic technologies is ill suited for D-^{3}He fuel burning.

SESSION II: M. OHNISHI

Effects of Nuclear Elastic Scattering on the Reactivity of D-^{3}He Fusion Plasmas

Y. Nakao discussed differences between D-^{3}He and other fuel power balance calculations, which are assumed to have a Maxwellian distribution of fuel-ion distribution, and the effect on fusion reactivity. D-^{3}He reactions depart from Maxwellian to a certain extent. The triton distribution function was cited as differing because of the presence of a 1.01-MeV birth component that results from a reduction in deuterium-tritium reactivity. Nuclear elastic scattering provided another mechanism for creating a non-Maxwellian distribution, one producing new energetic ions by recoil. The distribution functions of ion species other than triton also involve tail components. In this investigation of the degree of fuel-ion distribution functions and the effect on the reactivities of D-^{3}He plasma, a solution of the Boltzmann-Fokker-Planck equation for ignited plasmas was investigated. D-^{3}He appears to remain Maxwellian since the elastic scattering cross sections for p-^{3}He are small compared with those for p-D or p-T collisions and ^{3}He generation is considerably smaller than its fueling rate.

Self-Colliders for D-^{3}He Fusion

N. Rostoker noted the new look at IEC and emphasized the physics of ions. Electron physics is also important, particularly deceleration time, satisfying $(E_{fus}/E_{ion})\tau_f < \tau_i$. Self-consistent equilibria were obtained for high-beta plasmas where almost all of the ions are energetic with a gyroradius of the order of the plasma scale length. Magnetohydrodynamics (MHD) was noted not to apply to such plasmas. Recent tokamak experiments show that energetic ions slow down and diffuse according to classical theory. Anomalous losses occur only when there are large fluctuations of long wavelength and low frequency. If such instabilities are avoidable, the development of small reactors should be possible based on classical confinement. Several methods for creating such a plasma and calculations of a self-sustained reactor were reviewed.

SESSION III: J. SANTARIUS

Figures of Merit for Fusion Propulsion

N. Schulze presented space-unique fusion engine and space flight system design parameters and operational principles permitting the use of fusion energy for space power and propulsion. No real propulsion energy alternatives are available for use on high-energy missions beyond Mars such as human exploration and sample-return robotic missions. Fusion system solutions that meet those design parameters and operational needs are best addressed during investigations and research on confinement designs. Factors that are important to the terrestrial program and to space flight application can frequently be quite different. The importance of research to provide demonstrations was noted, particularly with maintaining stability during burning while removing plasma for propulsion, a significant issue in making magnetic fusion reactors practical for space propulsion. Burning efficiency will be important for long-duration missions. Key mission parameters, including specific power, power levels, thrust, firing duration, specific impulse, and mission quality aspects, were defined, and figures of merit were presented. Space operation of a fusion reactor offers relief from the vacuum constraint that ground systems are required to meet, but space vehicles are mass sensitive, requiring the use of a charged-particle-producing fuel like D-^{3}He and the use of compact reactors. To be useful, flight system aspects must weigh heavily on reactor research and design. The program requires great emphasis on reliability, safety, and environmental design provisions. Further, the technology must be "affordable." Reuse, space basing, and self-maintaining designs are important to provide cost-effective flight systems.

IEC Propulsion Design

The Nuclear Engineering 358 class at the University of Illinois is conducting a study, including laboratory investigations, on the use of IEC as a space propulsion system. The following students participated in the class project and presented this status report: A. Satsangi, J. Christiansen, D. Strellis, J. DeMora, T. Ochoa, S. Cooper, and J. Flurher. The system shows the attractiveness of a 3000-s specific impulse system. The IEC system provides a power source for an ion engine that can reach Mars with a manned crew in 120 days or less. Shielding from IEC and solar flares was a part of the discussion on safety. The IEC concept appears to be a reasonable candidate for providing high-specific-power flight systems, but further study is required before any definitive conclusions can be drawn. The class is progressing into the study, which was approximately at the midpoint into the semester.

SESSION IV: Y. NAKAO

Overview of Lunar ^{3}He Resources

J. Santarius discussed the status of the lunar ^{3}He mining program at the University of Wisconsin. An update was given on the progress being made. The point was made that ^{3}He is available on the moon and that mining appears to be feasible. Extensive use of completely robotic systems was the approach outlined. After a number of reviews by the U.S. mining community, the conclusion has been reached that moving the mass of regolith necessary for ^{3}He extraction is technically feasible. The lunar miner design was briefly described. The ^{3}He recovery technique has been well established. There is the additional advantage that a significant quantity of other valuable by-products, such as hydrogen, water, nitrogen, ^{4}He, methane, carbon dioxide, and carbon monoxide, are released during the recovery process. Viable legal frameworks for lunar ^{3}He mining have been identified. An examination of potential environmental effects has found no significant negative impacts. Mining only a small percentage of the ^{3}He will supply energy to the United States for 100 years. The cost estimates appear to be competitive. The net effect on the Earth's environment is very positive since the energy is being mined on another planet and is merely being transported to Earth in a refined state of readiness for use.

Steady Equilibrium of Field-Reversed Configuration Plasma Attributed to Fusion Protons

Y. Tomita discussed a novel approach for using a fueling seed current to obtain steady equilibrium. He showed that a pressure-gradient-produced particle injection or resultant diamagnetic current can sustain only an equilibrium of a diffused linear pinch. A seed current is needed for an extremely elongated FRC where the magnetic fields vanish. The seed current is produced by a directed flow of 14.68-MeV protons from a D-^{3}He reaction. Using steady-state burning with an anomaly factor of 500, he was able to sustain a 90% beta plasma by injecting large amounts of fuel particles at the plasma edge. Injection at the center reduced beta to 75%.

C. Choi had planned to present a paper on field-reversed configuration (FRC) stability but was unable to attend. The abstract he provided discussed the linear stability properties of an FRC using a nonlocal approximation.

SESSION V: N. ROSTOKER

Computational Studies of IEC

Y. Yamamoto discussed computational studies using two existing codes: the XL (Vlasov-Poisson solver) and PDS1 (one-dimensional particle-in-cell charged-particle simulation using a Monte Carlo collision calculation involving atoms) to understand an IEC plasma. Calculations showed that the "halo-mode" discharge (where "halo" neutron production = 2 × "star-mode" neutron production) is due to a double-potential-well structure. Limitations of XL were discussed: the need for inexpensive experimental test data (recirculation factors and ion and electron discharge current) and the limitation of considering only the region inside the grid. The effects of collisions were calculated using a modified PDS1 code to account for the IEC electrode geometry. The preliminary results showed that electrons emitted from the grid escape to the chamber wall very quickly. This showed that there was insufficient ionization in the outer region of IEC, especially at low pressure. Also it was shown that ions lose energy and are thermalized because of the high number of collisions. The results to date point out the need for a double grid in IEC. The double-grid discharge method showed IEC to be operational in the lower pressure regime, providing higher ion energy. Additional capabilities, such as fusion reaction calculations, are to be added.

Experimental Studies of IEC

J. Javedani described IEC experiment design, tests, and objectives. The IEC device has been determined to serve as a modest rate neutron source, and it will also enhance the understanding of IEC physics. The experimental device is a 30-cm-diam spherical stainless steel vacuum test chamber, having a concentric highly transparent negative biased (cathode) inner grid suspended inside. The cathode's potential is in the range of tens of kilovolts. Neutrons are produced from deuterium-deuterium (D-D) fusion reactions using a D_2 gas between electrodes in a steady-state discharge current of tens of mega-amperes. Neutron rates of $>10^6$/s have been produced, $V_{cath} = \sim 70$ kV; $i_{cath} = 15$ mA. Neutron rates of up to 10^8 are projected. There is already interest in the experiment as an inexpensive source of neutrons, an early application of the work. The probability of D-^{3}He fusion at ~70 keV is considered to be comparable with D-D. For data, they used light measurements of the Balmer β-line of deuterium plasma to investigate Bussard's inertial collisional compressional (ICC) theory. At low voltages, agreement was reached, whereas at high voltages, an increase in the light intensity to neutron ratio was observed, possibly a consequence of the ICC effect, which predicts an increase in the light intensity measurements at higher core densities. This was a status report, and the investigations continue.

Ion Beam Stabilization of Rotational Mode in an FRC

M. Ohnishi discussed an alternative method to control rotational instability of an FRC using injected "beam" ions to preserve the symmetry. Rotational instability can be suppressed by multipole magnetic fields that break the symmetry of the configuration. A multifluid model, for which a variational principle was developed and solved by using the Rayleigh-Ritz technique, led to an analytic solution for a rigid rotor equilibrium, allowing a derivation of marginal stability conditions. This was not possible with a previous hybrid simulation. The result was that rotational instability can be suppressed if the ratio of the rotational frequency of beam ions exceeds a critical value, resulting in the opposite radial displacement of beam ions and plasma. Compressibility effects of beam ions on stability were also examined. The analysis was applied to current or near-term experiments and to a future reactor. An important result was that the beam ion energy and current required is only a small fraction of that of the background plasma to stabilize rotational instability. A question was raised in the panel: Are the assumptions valid? Experimental data are needed.

SESSION VI: S. TANAKA

Attractive Characteristics and Critical Issues for a D-^{3}He-Fueled FRC Reactor

H. Momota discussed the results of a joint program for the comprehensive design of a 1-GW(electric) D-^{3}He-fueled FRC reactor, Artemis. Conventional engineering was applied to achieve plasma burning. The design showed attractive characteristics of the reactor for use as a commercial power plant. The high-beta design allowed the study team to make cost of electricity projections as low as 32 mill/kW·h, including the use of efficient direct converters. Burning D-^{3}He allowed a metallic material life projection of more than 30 yr. The volume and dosages from these materials are sufficiently small that surface disposal is considered environmentally acceptable. The issues identified were associated with the state of the art of current experimental plasma parameters with the required operational regime to which these designs need to expand. The importance of research on reasonable experimental devices to study equilibrium stability and transport for confinement was recognized, as was the need for verification of direct energy converters.

Ideal Stability of FRC Tilting and Local Modes

L. Steinhauer reported very favorable results from studies of the tilting mode, long the most feared instability in FRCs. Inferences from experimental observations indicate the presence of a *hollow* current density profile, i.e., reduced current density, in the neighborhood of the O-point. He noted that all previous tilting stability studies were done for equilibria with *peaked* current density. New work on the ideal MHD stability of hollow equilibria was presented. The method was a variational approach using the Rayleigh-Ritz method with up to three basis functions. It was found that tilting is ideal MHD stable if the separatrix is sufficiently "racetrack" and the current density is sufficiently hollow. One-third to one-half of a data set of past experiments fell into the tilt-stable regime. Those in the unstable regime were likely stabilized by finite ion orbit effects, which is not accounted for in ideal MHD theory. Importantly, it appears that some kind of internal relaxation mechanism maintains the FRC equilibrium in a state that is tilt stable. Steinhauer presented preliminary work on the ideal stability of local modes (e.g., interchange or ballooning) that may be responsible for the observed relaxation.

SESSION VII: Y. TOMITA

Proton-Driven Two-Energy Stream Cyclotron Instabilities and Associated Anomalous Processes in Magnetized Plasmas

K. Chen analyzed weak relativistic effects on the cyclotron frequencies of fusion-produced protons and ions that revealed a novel two-stream gyrospace even without beams in real space. This leads to a two-energy stream cyclotron instability for protons to drive waves and to slow down anomalously. The instability comes from the coupling of the proton and slow-ion Bernstein branches. The growth rate of the cubic instability is proportional to $(n_p/n_s)^{1/3}(\gamma_p - 1)^{1/3}$, while the efficiency is proportional to $(n_p/n_s)^{1/3}(\gamma_p - 1)^{2/3}$, where n = density and γ = Lorenz factor. Low proton harmonics in a deuterium plasma belong to the cubic instability, while a quadratic instability with a growth rate proportional to $(n_p/n_s)^{1/3}$ dominates at the high harmonics on a low hybrid band. Both linear and nonlinear scaling laws have been verified by their full kinetic particle-in-cell simulation with quiet start. The theoretical and simulation studies achieved good agreement with measurements of ion cyclotron emission in D-D experiments on the Joint European Torus (JET). The simulation results show that protons are anomalously slowed down, while some are accelerated to twice their birth energy; the fast ion density fluctuation and the phase bunching are large; and the background ions are heated up and become non-Maxwellian. The result is the same for protons in a D-^{3}He plasma.

p-^{11}B and D-^{3}He Fusion via IEC

T. Rider examined confinement of p-^{11}B and D-^{3}He in IEC. Issues included electron and ion losses, bremsstrahlung emission, and undesired side reaction rates [$^{11}B(p,\gamma)^{12}C$ and $d(d,n)^3He$]. He concluded that IEC appears to offer higher power densities, lower bremsstrahlung losses, and reduced side reactions in comparison with other confinement schemes using these fuels. The charged particles from the reactions offer the direct conversion of fusion products for highly efficient power systems. Additional work is still needed to evaluate IEC, but it appears possible to construct D-^{3}He reactors. It does not appear possible at this time to use p-^{11}B. Ion thermalization and upscattering losses are the greatest problems for either reaction. Bremsstrahlung is also a problem for p-^{11}B.

PANEL

A general discussion was held following the presentation of the papers. Session chairs presented a summary of each of the main topics and the key points raised. Many of the points presented are included in this summary. The next meeting will be held in Japan. Copies of the slides collected at this workshop are available from G. Miley, University of Illinois, Fusion Studies Laboratory, 103 S. Goodwin Avenue, Urbana, Illinois 61801.

G. Miley gave a tour of the University of Illinois Fusion Studies Laboratory during the afternoon of March 17, 1993. The participants were able to witness the plasma contained within the grids of the IEC, including the jet and star modes reported during the IEC discussions. The demonstrations were led by J. Javedani, A. Satsangi, and Y. Yamamoto.

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April 16, 1993

SUMMARY OF INTERNATIONAL SYMPOSIUM OF NEW ENERGY, DENVER, COLORADO, APRIL 17–18, 1993

INTRODUCTION

Some 20 scientists, inventors, and writers from various countries gathered for a 2-day retreat and symposium on new energy on April 14–16, 1993, at Estes Park, Colorado, sponsored by the International Association for New Science (IANS). Subsequently, members of this group were the keynote speakers at a 2-day symposium on new energy held April 17–19, 1993, in Denver, Colorado.

Cold fusion, over-unity energy machines, solid-state excess energy devices, and zero-point energy (ZPE) devices were some of the subjects discussed. This gathering of the world's leaders in new energy devices was an historic first. The end results are expected to accelerate the development and commercialization of some of the new energy systems now being developed.

An example of one of the leading new energy devices is the Tewari motor-driven generator, which produced high-amperage, low-voltage power equal to about three times the power used to run the electrical motor. P. Tewari is the chief project engineer of the Kaiga project in India, where this device has been under development for more than 10 years.

HIGHLIGHTS OF THE RETREAT

The objective of the retreat was to get the world's top scientists, inventors, and writers in the field of new energy together. There were beneficial results from the face-to-face meeting, the sharing of information, and the informal arrangements for cooperation in practice and theory. The outcome of the meeting was the decision to form the Institute for New Energy, to publish the *New Energy News* newsletter, and to hold future retreats, workshops, and conferences; in other words, to facilitate communication.

Those invited to the retreat were associated with new, nonstandard, or unusual methods of producing energy. Some were theoreticians with splendid credits for technical publications, such as Harold Aspden, Peter Graneau, and Stefan Marinov. Others could be counted as determined experimentalists who are finding methods to provide new, nonpolluting sources of energy, such as Don Kelly, Troy Reed, and Tewari. Others could be classified as reporters or writers, such as Hal Fox and Moray King.