or X-ray source for laser pumping and for projectile acceleration were discussed.

### Mirror Device Plasmas

The basic mirror device is the simplest machine offering a useful degree of hot plasma confinement. In particular, the good confinement of high-energy particles makes the device useful in ECR heated and neutral beam applications. The simplicity of the mirror makes it attractive in practical nonfusion applications. This session included papers that described the application of mirrors to accelerators, high-charge-state ion and X-ray sources, neutron sources for fusion materials research, and wave-plasma research involving cyclotron heating, pondermotive force, and potential control studies.

### Electromagnetic Launchers

This session considered accelerators or "guns" designed to use electrical energy to accelerate or launch either solid projectiles or well-organized plasmas at hypervelocities for target impact or appropriate equation-of-state studies. The session contained discussions of railgun operation in fairly standard configurations including experimental studies of several different railgun systems; experimental and theoretical analysis of plasma armature driving the sabot and projectile down the gun bore; measurement and analysis of erosion of the rail electrodes or insulator materials; design and use of specially configured diagnostic probes to measure the drive current profile; and a discussion of problems of plasma restrike in undesirable locations, which tend to limit performance to no more than 8 km/s. Additional papers described approaches planned or under study to reduce or eliminate troublesome rail and insulator erosion problems, e.g., use of a gas gun for first-stage high-velocity injection into a high-speed railgun bore, or use of a conductor configuration tending to magnetically shield critical surfaces. Also, several very different gun configurations were discussed. The limit of railgun performance with only a plasma armature was explored. In an invited paper, J. E. Osher (LLNL) reported on an "electric gun" that uses an exploding metal foil and $J \times B$ forces in a very short gun configuration to drive thin plastic solid flyers up to 20 km/s. Proposals to use electrothermal expansion or coaxial magnetic compression to drive projectiles to hypervelocities were presented. Finally, the theory and operation of a coaxial plasma gun driving high-energy density magnetized plasma to extremely high velocities was described.

### Free Electron Lasers

The theoretical modeling of free electron laser (FEL) physics is becoming more sophisticated, and the number of experiments is increasing. A major advance in FEL theory is in the area of radiation self-focusing. Radiation focusing plays a central role in the practical utilization of the FEL since in many proposed experiments the radiation beam is not confined by the waveguide structure. Correct use of the self-focusing property can enhance the FEL gain and efficiency. For the first time, algebraic expressions were reported for guiding the beam in the small-signal, exponential growth regime. This was reported in an invited paper by P. Sprangle (NRL). Simple expressions for the growth rate, intrinsic efficiency, radiation spot size, and wave-front curvature were obtained. The analytic expressions are in good agreement with fully nonlinear three-dimensional simulations.

Many FEL experiments were proposed, and two experimental results were reported. The Mark II FEL at Hughes Research Laboratories provided stable, single-mode, linearly polarized emission for 10 $\mu$s at 35 GHz with a linewidth of 200 kHz. Recent experiments on the Electron Laser Facility at LLNL, which uses the Experimental Test Accelerator (3.5 MeV, 1 kA) and an electromagnetic wiggler (4.0 m, 4 kG), were described. Operation was extended from 35 to 140 GHz by using a 250-W extended interaction oscillator as the source and operating at reduced wiggler fields. The radiation grew exponentially in the wiggler and was observed to saturate at 100 MW near the end of the wiggler (3.4 m). No significant gains were obtained by tapering the wiggler after saturation, due to lack of wiggler interaction length. The measured output powers and gain were in good agreement with simulations.

## CONCLUSION

The technical program of the conference was promoted and arranged by the session organizers who provided the conference chairman with technical summaries of their session topics. These were edited by the chairman to prepare this conference report. The session organizers are identified in the conference record. Presentations to the conference are documented in the Conference Record—Abstracts of the 1987 IEEE International Conference on Plasma Science, which is available from the Director, Publishing Services, IEEE, 345 East 47th Street, New York, New York 10017.

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## SUMMARY OF THE 13TH INTERNATIONAL SYMPOSIUM OF EFFECTS OF RADIATION ON MATERIALS, SEATTLE, WASHINGTON, JUNE 23–25, 1986

This biennial symposium series is sponsored by the American Society for Testing and Materials (ASTM) Committee E10 on Nuclear Technology and Applications. The series began in 1960 and has become a major international forum for the exchange and discussion of both fundamental and technological aspects of behavior change in materials exposed to radiation environments. The data presented at this meeting were primarily concerned with the response of metals to neutron or charged-particle irradiation although there were a number of papers directed toward nonmetallic materials. As in the past, the performance of nuclear fuels was not included since this topic receives adequate treatment in other forums.

The thirteenth symposium reached a record level of participation, necessitating its publication in two separate proceedings. This report is organized in the order that was used to compile the proceedings.

ASTM STP 955, *Radiation-Induced Changes in Microstructure*, F. A. Garner, N. H. Packan, and A. S. Kumar, Eds.

This first portion of the proceedings contains the majority of the papers presented in those sessions directed toward the production by radiation of point defects, their subsequent diffusion, and their consequences on microstructural evolution, phase changes, and dimensional stability in metals.

In the first section of this portion of the proceedings, *Radiation-Induced Defects and Their Diffusion*, several papers address the production and diffusion of point defects in various metals, exploring the effect of crystal structure, composition, and type of bombarding particle. Four of these papers investigate the collapse of defect cascades in materials ranging from pure metals to ordered alloys.

In *Neutron-Induced Swelling*, a large amount of recent data is presented, which explores in a wide variety of face-centered-cubic (fcc) metals and alloys the dependence of void swelling on composition, metallurgical state, and reactor environment. One significant new conclusion is that compressive stresses are as effective as tensile stresses in accelerating the onset of swelling. Previous theoretical treatments predicted that compressive stresses would retard swelling.

In *Charged-Particle-Induced Swelling*, a variety of particles are used to simulate the swelling induced by neutrons. These particles include electrons, self-ions, and very energetic (600-MeV) protons. Several significant new conclusions are presented in these papers. First, it is shown that the compositional dependence of swelling in Fe-Cr-Ni alloys tends to decrease upon addition of helium, suggesting that composition differences will exert less influence in fusion devices compared to fission devices. Second, it appears that in Fe-Mn-Cr alloys, iron is the element that segregates to sinks whereas in Fe-Ni-Cr alloys, it is nickel that segregates. This difference suggests that Fe-Mn-Cr alloys will be much more susceptible to formation of ferrite than are Fe-Ni-Cr alloys. Fe-Mn-Cr alloys have been proposed for fusion service.

The section, *Theory of Swelling and Irradiation Creep*, is much larger than that of previous symposia, reflecting the growing maturity of our understanding of these phenomena. Three papers address the influence of helium, and a number of others are concerned with the evolution and role of both preexisting and radiation-induced microstructural components. Two papers address the compositional dependence of swelling, invoking the influence of composition on vacancy diffusivity. One paper is directed toward the swelling of metal fuel.

The experimental results presented in *Microstructural Evolution* cover a wide range of materials, environmental variables, and bombarding particles. A similar statement can be made concerning the section, *Solute Segregation and Phase Stability*. Together, these two related sections comprise the majority of papers in this portion of the proceedings. A variety of previously unexpected phase instabilities are uncovered in these two sections, indicating that much remains to be discovered concerning the influence of radiation on phase stability. It also appears that the displacement gradients inherent in charged-particle irradiation have an even larger impact on solute segregation, phase stability, and swelling than previously thought possible.

The four papers in the last section, *Effects of Gas Implantation*, explore the influence of helium and hydrogen on the damage introduced into a variety of materials ranging from metals and intermetallic compounds to metallic glasses.

ASTM STP 956, *Influence of Radiation on Material Properties*, F. A. Garner, C. H. Henager, Jr., and N. Igata, Eds.

This second portion of the proceedings contains the majority of the papers presented in those sessions devoted to creep, creep rupture, and changes in mechanical properties of metals and alloys. Also included are papers on radiation damage in nonmetals, papers that describe irradiation facilities, and papers on the dosimetry of radiation environments.

The first section, *Irradiation Creep and Creep Rupture*, focuses on the in-reactor creep and creep rupture behavior of both simple metals and engineering alloys. It is argued in one paper that the use of unirradiated and postirradiation data for predicting in-reactor behavior is invalid. Another paper discusses low-dose irradiation creep mechanisms in model ferritic alloys and demonstrates that intrinsic bias differences between fcc and body-centered-cubic metals do not affect climb-glide creep rates. One new conclusion of another study was that irradiation creep in AISI 316 appears to disappear at swelling levels in the range of 5 to 10%.

The second section, *Changes in Mechanical Properties of Alloys*, explores changes in strength, fracture behavior, fracture toughness, fatigue crack growth, and fatigue crack initiation occurring in a wide variety of important engineering alloys due to irradiation. Due to their unique problems, pressure vessel steels are not included in this section.

In *Pressure Vessel Steels*, both fundamental data on irradiation embrittlement and statistical studies of data bases are presented and discussed in a number of papers. Positron annihilation and small angle neutron scattering techniques are explored, which provide information on submicroscopic clustering in these alloys. Mechanical property data are also presented, which address the possibility of thermal recovery of neutron-induced damage.

The section, *Radiation Damage in Nonmetals*, is significantly larger than that of previous symposia and contains discussions on polymeric, glass, lithium-containing ceramic, and elastomeric materials in radiation environments. Papers were presented on cable connectors, glass fibers, polymide film, ophthalmic preservatives, reactor seals, and radioactive waste forms.

*The Irradiation Facilities* section contains discussions on major irradiation facilities available to qualified users. Facilities at Idaho National Engineering Laboratory are described, as well as the Los Alamos Spallation Radiation Effects Facility and the National Low Temperature Neutron Irradiation Facility at Oak Ridge.

The section, *Dosimetry of Radiation Environments*, explores topics in neutron dosimetry and damage analysis, radiation damage prediction, and neutronics of fusion environments.

Copies of the proceedings were expected to be available in November 1987 and can be ordered directly from ASTM, 1916 Race Street, Philadelphia, Pennsylvania, 19103.

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