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Mechanical Engineering Department Technical Abstracts

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Preface

The Mechanical Engineering Department publishes listings of technical abstracts twice a year to *inform readers of the broad range of technical activities in the Department, and to promote an exchange of ideas. Details of the work covered by an abstract may be obtained by contacting the author(s).*

Overall information about current activities of each of the Department's seven divisions precedes the technical abstracts. *Specific information about technical activities may be obtained from division leaders (listed at the end of each divisional summary) or from members of the ME Technical Review Committee.*

Committee members are as follows:

R.B. Carr, Deputy Department Head
E.W. McCauley, Nuclear Test Engineering Division
D.W. Ravenscroft, Nuclear Explosives Engineering Division
J.H. Pitts, Energy Systems Engineering Division
A.S. Zolnay, Weapons Engineering Division
R.H. Bossi, Engineering Sciences Division
J.D. Lee, Magnetic Fusion Engineering Division
H.H. Humpal, Materials Fabrication Division
R.M. Denney, *General Editor.*

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Divisional Activities

Nuclear Test Engineering Division

The Nuclear Test Engineering Division (NTED) provides mechanical engineering and technical expertise for a wide range of activities in three LLNL programs: nuclear test, nuclear systems safety, and energy.

Nuclear Test Program

Our nuclear testing responsibilities involve design, structural evaluation, fabrication, and proof testing of diagnostic and device canisters that position radiation detectors and protect nuclear explosives in an underground environment. We synthesize, procure, and certify the arming and firing systems, and we develop downhole and containment systems to meet zero-detectable radioactivity release requirements. Our advanced development projects include studies of new engineering concepts, analytical and design methods, and diagnostic techniques. In carrying out this work, we strive to improve data quality and field operations, maximize safety, and optimize cost-effectiveness and resource utilization. Included in this programmatic support is spill effects testing under the Liquefied Gaseous Fuels Program.

Nuclear Systems Safety Program

The safety of nuclear power plants and associated facilities is the major concern of the Nuclear Regulatory Commission (NRC). We are responsible for providing technical data relating to reactor safety on which the NRC can base licensing decisions and assessment tools to protect public health and safety. Facilities in the nuclear fuel cycle—processing and fabrication, reactor containment systems, interim waste storage, and spent fuel reprocessing—are considered from the viewpoint of safety and structural integrity.

Our multidisciplinary work is grouped into four categories: seismic and structural safety, reactor engineering, systems/operations, and licensing reviews. *The NRC relies on the Laboratory as the primary facility for research on the seismic safety of nuclear power plants. Our multiyear Seismic Safety Margins Research Program (SSMRP), for example, defines the adequacy of seismic design*

for the safety of nuclear power plants in the U.S. Reactor engineering work involves accident analysis and studies of thermal-hydraulic and fluid-structure interaction phenomena. Systems/operations projects are concerned with risk assessment and control room design reviews. We also provide technical assistance to the NRC licensing staff on reactors operating or under construction.

In addition, our engineering mechanics expertise is applied to specific projects in other areas, including effort for the Magnetic Fusion Program, the Plant Engineering Department, H Division, and W Division.

Energy Program

We provide mechanical engineering support to several of the Laboratory's smaller energy projects and to a number of efforts for the Earth Sciences Department. Current work is under way in oil shale retorting, underground coal gasification, radionuclide migration, spent reactor fuel storage, and geophysics research. We are responsible for designing, building, and operating both Laboratory experiments and off-site field engineering tests.

(For further information, contact R.J. Wasley, Ext. 2-9966.)

Nuclear Explosives Engineering Division

The Nuclear Explosives Engineering Division's (NEED) major mission is to support the Laboratory's Nuclear Design Program (NDP). The activities include fielding nuclear devices for Nevada Test Site expenditure. The division also supports the Nonnuclear Ordnance Program, Military Application Program (phase 1 and phase 2 studies), and H (physics) Division. In addition, NEED performs studies and develops hardware for Y-program, Z Division, and the Defense Nuclear Agency.

The Nuclear Explosives Engineering Division's project teams are dedicated to specific engineering areas: conceptual nuclear design, strategic systems, development and production/liaison for

nuclear devices, advanced fission and fusion systems, hydrodiagnostic development, and maintenance and upgrade of many test facilities at Site 300. The Division's applied mechanics group supports Laboratory programs with calculational expertise in solid mechanics and transport phenomena. The auxiliary systems group supports the Laboratory programs with expertise in high pressure gas technology; NEED also provides staff members for facilities used to conduct high pressure gas and liquid experiments. Certified tubing, valves, and other components or equipment are supplied for gas handling systems.

(For further information, contact R.A. Corallo, Ext. 2-8307.)

Weapons Engineering Division

The Weapons Engineering Division (WED) is responsible for engineering activities supporting nuclear weapons development, production, and maintenance of an important portion of the national stockpile. In providing these services, the Division keeps abreast of new developments in safety and weapon control.

The activities include new weapon development, environmental testing, weapon control, initiation of systems development, engineering technology, and special materials procurement. Production work involves communicating product definition and design intent to the DOE contractors responsible for component fabrication and assembly. In addition, active monitoring of the stockpile requires a careful effort in disassembly surveillance of stockpile weapons to ensure that design requirements have indeed been met and to monitor physical changes that may eventually limit the useful life of a weapon.

The Special Materials (SM) office in WED purchases goods and services from the DOE contractors, military commands, and other governmental agencies for all LLNL programs. This office is also responsible for coordinating Laboratory guidance on weapon development activities by the DOE contractors, purchasing special isotopes used in a variety of programs, and providing the DOE with a forecast and management plan on nuclear material usage.

(For further information, contact R.E. Clough, Ext. 2-8296.)

Energy Systems Engineering Division

This division is engaged in a variety of work to provide mechanical engineering support to the Laser (Y) Program in two major categories: Laser Isotope Separation (LIS) and Inertial Confinement Fusion (ICF). In the LIS program, coherent laser light is used to selectively photoionize atoms of a given isotope in a material containing several isotopes. The ionized atoms can then be separated and enriched using extractor/collectors. The ICF effort is directed at understanding the basic physics problems associated with imploding small fusion targets with high power lasers, and at developing a fusion process to provide an unlimited source of power for use during the next century. Each major category has both military and civilian applications.

(For further information, contact J.E. Keller, Jr., or J.R. Hauber, both at Ext. 2-7582.)

Engineering Sciences Division

The Engineering Sciences Division (ESD) provides complete technical services to LLNL programs for materials characterization, engineering measurements, nondestructive evaluation, and mechanical systems design and evaluation. The Division has more than 20 separate laboratories and facilities that are organized into sections responsible for specific technological areas.

The Materials Test and Evaluation Section provides mechanical testing, such as ASTM standard tests and special tests tailored to individual customer requirements. Developments are carried out in the fields of acoustic emission, fracture mechanics, high-rate material response, experimental stress analysis, and composite materials in order to characterize and improve engineering designs.

The Engineering Measurements Section is engaged in work ranging from the design of a single transducer to the fielding of complete measurements systems. Service for the calibration and installation of transducers and accelerometers is also available.

The Nondestructive Evaluation Section provides inspection and diagnostic testing services to LLNL programs. X-ray and gamma source radiography, radiation gauging, ultrasonics, eddy current, dye penetrant, magnetic particles, and holographic techniques are available.

The Engineering Design Section performs design, analysis, and mechanical fabrication in support of the Chemistry and Materials Science Department and many ESD projects. The section is particularly experienced in automated machine design, composites processing and fabrication, tritium handling, mass spectrometry, and high explosives technology.

The Life Sciences Section provides mechanical engineering support for Biomed and Environmental Research, Hazards Control, and Toxic Waste Management programs. Examples of developments to meet the varied requirements of these groups include a cell sorter in Biomed, personnel dosimetry equipment in Hazards Control, and storage and/or burial containers for toxic wastes.

The LLNL Plutonium Facility is managed by the Chemistry and Materials Science Department with operational support provided in part by ESD. The Plutonium Engineering Section in ESD provides engineering design, fabrication, and testing services for the Facility and its users.

The Transportation Systems Research Section participates in research projects for the Department of Energy, Department of Transportation, and other agencies. Projects range from metal-air batteries and powered roadways to the engineering evaluation of various transportation technologies and their impact on the nation's transportation.

(For further information, contact R.W. Werne, Ext. 2-8360.)

Magnetic Fusion Engineering Division

The Magnetic Fusion Engineering Division (MFED) supports the LLNL physics programs in four principal areas:

- Magnetic fusion energy (MFE) confinement experiments.
- MFE development and technology.
- Particle beam development.
- High energy physics.

The four areas share a common technological base, although their individual goals differ greatly. Each area requires support from essentially all mechanical engineering disciplines and from specialists in normal and superconducting magnetics, cryogenic systems, vacuum systems, high-voltage components, and nucleonics.

Our role in the MFE confinement experiments is to provide systems engineering and to

design and fabricate mechanical hardware. The research in magnetic mirror confinement of nuclear fusion reactions is expected to lead to utilizing deuterium, an isotope of hydrogen present in sea water, as a nearly inexhaustible energy source. The major confinement experiments are the Tandem Mirror Experiment (TMX), Beta II (formerly 2XIIIB), and the Mirror Fusion Test Facility (MFTF).

In MFE development and technology, our mission is to develop the technical base and engineering skills necessary to meet future needs of magnetic confinement systems. Our active programs are the development of a multifilamentary Nb₃Sn superconductor, high-vacuum technology, and fusion reactor studies. Basic research and development are emphasized to lay the groundwork for future fusion experiments.

The particle beam development program, funded by the Defense Advanced Research Projects Agency (DARPA), involves building high-current, high-voltage, electron accelerators. Such accelerators are of interest for basic physics research and in the weapons community. The present program calls for developing two accelerators, the Experimental Test Accelerator (ETA) and the Advanced Test Accelerator (ATA). The ETA program is the predecessor to the ATA, and it will generate the technology data base to build the 10-kA, 50-MeV ATA machine.

Our role in high energy physics is to provide tools with which to pursue fundamental understanding of energy and matter. Technical support is provided for experiments performed at the 100-MeV electron linear accelerator (Linac)—three 400-keV dc high-current accelerators, a 3-MeV electrostatic accelerator, a 6-MeV tandem electrostatic accelerator, and a 76-cm cyclotron.

The MFED consists of seven project groups plus a division office.

(For further information, contact H.L. Galles, Ext. 2-8296.)

Materials Fabrication Division

The Materials Fabrication Division, a multidisciplinary organization in the Mechanical Engineering Department, provides services that are not available from commercial sources. The number and diversity of LLNL research efforts make this division one of the Laboratory's largest. We

have about 450 highly skilled persons and more than 3,700 pieces of equipment in our inventory.

With these facilities and the special capabilities of our staff we provide services in the fields of optics, welding, vacuum process, glass, plastics, sheet metal, metal finishing, metrology, pressing, inspection and assembly, as well as conventional and numerically controlled machining of metals, high explosives, and ceramics.

In-house fabrication services are available for all LLNL programs when requirements call for:

- Fabrication capabilities not readily available elsewhere.

- Rapid turnaround time.

- Handling of materials that are toxic, radioactive, or classified.

In addition, the Division's facilities are used to develop improved manufacturing techniques and to advance machine tool research. Our operating philosophy is to satisfy the mechanical fabrication need of the programs, consistent with priorities set by those programs.

(For further information, contact D.K. Fisher, Ext. 2-7643.)

Publication Abstracts*

T.W. Alger and W.J. Benett, *Sealed Copper Vapor Laser Assembly*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-85710 (1981). Prepared for Review of Scientific Instruments.

Improvements in a discharge heated copper vapor laser (CVL) assembly may result in greater long term performance and reliability. This new design incorporated a positive gas seal to allow high pressure sealed or controlled leak rate operation. High pressure operation at low buffer-gas leak rates results in a decrease in copper loss rate and, because of this, an improved useful lifetime. A description of materials and construction method for this copper vapor laser assembly is provided.

D.S. Baily, Y.T. Lee, and R.M. More, *Ab Initio Calculation of the Charge State of Fast Heavy Ion Stopped in a Finite Temperature Target*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86393 (1981). Prepared for the 23rd Annual Meeting, American Physical Soc., Division of Plasma Physics, New York, NY, October 12-16, 1981.

As a result of recent interest in using heavy ion drivers for ICF targets, we are trying to improve our stopping power calculations. An essential part of the stopping power is a knowledge of the effective charge of the projectile, since the square of that charge state of a heavy ion stopping in a general target has been calculated from first principles by the use of an average atom model to integrate the rate equations. The rates of (non-Maxwellian) electron bound-bound excitation and bound-free ionization processes together with radiative recombination are included. The sub-shell splittings are represented by a quantum-defect representation improvement of a Slater screening model. The results will be compared to the empirical Betz formula.

C.F. Baker, C.Y. King, J.W. Lyle, R.K. Mullins, D.S. Ravenscroft, and W.M. Shay, *Response of the Flash X-Ray Building at Site 300 to Explosions on Its Firing Table*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-53175 (1981).

The response of the new high-explosive Flash X-ray Radiography Facility at Bunker 801 at LLNL

*The abstracts are arranged alphabetically by first author's name.

Site 300 to explosions on its firing table has been measured. Seven charges of the high explosive C-4, with increasing weights of from 18 to 585 lb, were detonated. Charges were placed on a pea-gravel firing table on the radiographic axis 10 ft from the face of the steel bullnose protection plate. No noteworthy damage to the new building or its installed equipment occurred during these tests.

Strains on 46 strain gauges were recorded during the explosive tests. During construction of the facility, these gauges had been welded to the steel reinforcing bars in various locations, or suspended between them, and were then embedded in the structural concrete. The gauges recorded strains as high as 220 $\mu\text{in./in.}$, which is equivalent to a stress of 5600 psi in steel. All elements of the structure remained well below their elastic limits, and should remain within these limits when subjected to detonations of up to 1000 lb of TNT on the firing table.

The measured strains were less than those given by simple engineering calculations by factors of from 1.7 to 3.9. Several safety factors and conservative simplifying assumptions were included in the strain calculations, and this may account for the large differences.

Work is underway with more elaborate structural-analysis models that use the Laboratory's large digital computers. Future experiments and computer modeling should yield better agreement between theory and experiment.

T.G. Beat, G.E. Griggs, and J.W. Dini, *Quantitative Adhesion Data for Two Energetic Physical Vapor Deposition Processes*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87010 (1981). Prepared for Proc. 2nd American Electroplaters' Soc. Symp. on Plating on Difficult-to-Plate Materials, St. Louis, MO, March 25, 1982.

This paper provides quantitative ring shear adhesion data for copper plated on titanium (Ti-6Al-4V) by the hot hollow cathode physical vapor deposition process and copper plated on 304 stainless steel by magnetron ion plating. These are the first known published data of this type for physically vapor deposited coatings and they show that adhesion on difficult to plate substrates was quite good and compares favorably with data for electrodeposited coatings on similar substrates.

D.D. Berger, "Joining Tantalum to Alumina by Brazing," *Welding Journal* 60, 25 (October 1981).

A technique was needed for joining alumina to tantalum in order to provide a reliable and reproducible leaktight seal between the ends of an alumina tube and tantalum electrodes. The assemblies are for a new generation of lasers for the Laser Isotope Separation Program at the Lawrence Livermore National Laboratory. The vacuum brazing process used to make the joint is described.

D.D. Berger, *Mounting a Calcium Fluoride Window*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87050 (1981). Prepared for the *Review of Scientific Instruments*.

A technique has been developed for joining a large calcium fluoride (CaF_2) crystal to a stainless steel flange by means of a silver transition ring. The crystal was needed as an exit window of a Gas Scintillation Proportional Counter at LLNL.

The original objective was to develop a means of joining a 14.6-cm diam by 1-cm thick (5-3/4 by 3/8 in.) CaF_2 exit window to one end of a 14-cm o.d. (5-1/2 in.) Al_2O_3 tube. The following application requirements had to be considered:

1. The Al_2O_3 to CaF_2 joint did not necessarily need to be vacuum tight, but it did need to contain and separate atmospheres of different high purity gases.

2. The entire system needed to be capable of being baked out at a temperature of at least 150°C.

3. The CaF_2 window had to be detachable from the Al_2O_3 tube.

4. No metal could be allowed to project into the bore of the counter.

5. Sources of contamination (e.g., elastomer O-rings) had to be kept to a minimum.

The approach chosen to satisfy all the above requirements consisted of attaching the CaF_2 crystal to a flange which could then be bolted, and O-ring sealed, to a mating flange that was brazed to the Al_2O_3 tube. This paper describes the technique used to join the CaF_2 window by means of a silver transition ring to the flange.

A. Blake and D.D. McDaniel, *Collapse of Cylindrical Fiberglass Canisters Under External Pressure*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86957 (1981). Prepared for the 1982 Joint Conf. on Experimental Mechanics of the Soc. for Experimental Stress Analysis, Honolulu, HI, May 22-30, 1982.

This paper presents the results of external pressure experiments and the related strength tests for cylindrical fiberglass canisters constructed by conventional fabrication techniques. The results of the collapse tests are correlated with the theoretical predictions taking into account the actual out-of-roundness and the mechanical properties derived from tests. This investigation indicates a promising area of fiberglass canister development for external pressure and similar containment applications.

B.M. Boghosian, R.B. Campbell, and J.M. Gilmore, *A Potential Solver for Sloshing-Ion Thermal Barriers*, Lawrence Livermore National Laboratory, Livermore, CA, UCID-19215 (1981).

The quasi-neutrality equations at points (a) and (b) in a sloshing-ion thermal barrier are derived and an algorithm for their solution is given. The solution technique is sufficiently reliable and efficient to be used in a fluid code where it must be invoked at each time step. Circumstances under which the equations admit multiple solutions are noted and discussed.

R.H. Bossi and C.T. Oien,* *Real-Time Radiography*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-53091 (1981).

Real-time radiography is used for imaging both dynamic events and static objects. Fluorescent screens play an important role in converting radiation to light, which is then observed directly or intensified and detected. The radiographic parameters for real-time radiography are similar to conventional film radiography with special emphasis on statistics and magnification. Direct-viewing fluoroscopy uses the human eye as a detector of fluorescent screen light or the light from an intensifier. Remote-viewing systems replace the human observer with a television camera. The remote-viewing systems have many advantages over the direct-viewing conditions such as safety, image enhancement, and the capability to produce permanent records. This report reviews real-time imaging system parameters and components.

*With Sandia National Laboratories, Livermore, CA.

R.H. Bossi, A.H. Robinson, and J.P. Barton,* *High Frame-Rate Neutron Radiography of Dynamic Events*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86954 (1981). Prepared for the Proc. of the the World Conf. on Neutron Radiography, San Diego, CA, December 7-10, 1981.

A system has been developed to perform neutron radiographic analysis of dynamic events having a duration of several milliseconds. The system has been operated in the range of 2000 to 10,000 frames/s. Synchronization has provided high-speed-motion neutron radiographs for evaluation of the firing cycle of 7.62-mm munition rounds within a steel rifle barrel. The system has also been used to demonstrate the ability to produce neutron radiographic movies of two-phase flow.

The equipment uses the Oregon State University TRIGA reactor capable of pulsing to 3000-MW peak power, a neutron beam collimator, a scintillator neutron conversion screen coupled to an image intensifier, and a 16-mm high speed movie camera. The peak neutron flux incident at the object position is approximately 4×10^{11} n/cm²s with a pulse, full width at half-maximum, of 9 ms.

Special studies have been performed on the scintillator conversion screens and on the effects of statistical limitations on the image quality. Modulation transfer function analysis has been used to assist in the evaluation of the system performance.

D.M. Boyd, J.F. Shackelford, B.W. Maxfield, and G.M. Taylor, *Nondestructive Evaluation of Electron Beam Braze Joints*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87517 (1982). Prepared for Materials Evaluation, The American Society for Nondestructive Testing.

A nondestructive evaluation (NDE) program has been carried out using holographic interferometry, microradiography, and eddy current testing for the inspection of electron beam braze joining of dissimilar metals. Stainless steel tubing was joined to a gold-copper disk using a Cusil (copper/silver) brazing alloy. Holographic interferometry provided an indirect measure of strength by detecting the plastic deformation occurring as a result of applying a stress. Microradiography with the aid of computer graphics dis-

plays provided a means of measuring braze penetration into the stainless steel tube. Correlation of results with metallographic examination and microhardness measurements shows that holography and microradiography each provide quantitative braze quality rankings. Each method correctly identified variations in braze quality independent of electron beam power (the only processing variable in sample fabrication). Eddy current results were consistent with the other NDE methods but appear to be based on variation in surface topography rather than electrical conductivity. The usefulness of the eddy current method for this problem is questionable due to its sensitivity to the small, complex test piece geometry.

D.M. Boyd and William M. Wilcox, *Weld Evaluation on Spherical Pressure Vessels Using Holographic Interferometry*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-84079 (1982). Prepared for *Experimental Techniques*, Society for Experimental Stress Analysis.

Waist welds on spherical experimental pressure vessels have been evaluated under pressure using holographic interferometry. A coincident viewing and illumination optical configuration coupled with a parabolic mirror was used so that the entire weld region could be examined with a single hologram. Positioning the pressure vessel at the focal point of the parabolic mirror provides a relatively undistorted 360-deg view of the waist weld. Double exposure and real-time holography were used to obtain displacement information on the weld region. Results are compared with radiographic and ultrasonic inspections.

A.E. Brown, G.E. Faulkner, and C.A. Tatro, *Investigation of Acoustic Emission Response from Laser Welds II*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86928 (1981). Prepared for the 23rd AEWG Meeting, Toronto, Canada, December 1-3, 1981. Also for publication in the *Journal of Acoustic Emission*.

Initial attempts at monitoring acoustic emission (AE) generated from laser welds indicated a correlation existed between the AE and the weld. Phase II of this investigation involved more sophisticated techniques in AE instrumentation. These techniques included windowing and categorizing the AE with respect to the timing of a pulsed laser system.

*Consultant, La Jolla, CA.

A.E. Brown, C.A. Tatro, G.E. Faulkner, and S.J. Vahaviolos,* *Acoustic Emission Monitoring of Laser Fusion Welding*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87222 (1982). Prepared for the ASNT Spring Conf., Boston, MA, March 22-25, 1982.

As components become smaller and requirements for increased strength and reliability are increasing, laser welding is becoming the preferred method of fastening some metals. However, due to the relatively shallow depth of penetration and narrow width of the weld bead, small changes in several parameters of the weld can dramatically affect the weld integrity.

Over the past year, a limited amount of effort has been applied to determine the effectiveness of acoustic emission techniques in in-process monitoring of laser welds.

University of California Lawrence Livermore National Laboratory (UCLLNL) contracted for feasibility studies in the application of instrumentation to monitor the acoustic emission generated during laser welding and electron beam welding. Feasibility was demonstrated using a CO₂ laser in the pulsed mode.

UCLLNL subsequently purchased an acoustic emission system for in-process monitoring of YAG laser welds. The material of local interest was 316 stainless steel bands, 0.010-in. thick by about 1.0-in. wide (0.25 by 25 mm). The bands were placed face to face with the edges parallel and level. A computer controlled (CNC) laser weld system was coded to pass the clamped bands through the pulsed laser beam, laying the weld bead along one edge of the bands. The laser beam width was controlled by the focal length to about 0.020 in. (0.5 mm). The depth of weld penetration was affected by the aperture size, height of the bands above the chill block (clamp), and laser pulse duration and energy. A standard, or "parameter", weld was to receive a 5.46-ms pulse of laser light every 250 ms. The bands were moved through the laser at a velocity that would permit a 70% overlap of the weld nuggets.

N.J. Brown, *A Short Course on Optical Fabrication Technology*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86796 (1981). Prepared for the Optical Soc. of America, Annual Meeting, Orlando, FL, October 26-30, 1981.

This course covers optical shapes, the wear equation, the grinding and polishing of glass, the polishing of metals, the mechanics of polishing machines, the figuring and polishing of platelike and tubular optics, and simple shop calculations. Emphasis throughout is on numerical methods.

S.E. Bumpus, *Seismic Response Spectrum Analysis Incorporating All Modal Mass*, Lawrence Livermore National Laboratory, Livermore, CA. Contact Nuclear Test Engineering Division for SM 81-211.

A series of codes have been assembled to perform a response spectrum analysis of a structure in accordance with procedures outlined in recent recommendations to the Nuclear Regulatory Commission. This series of codes uses the SAP4 model to obtain mode shapes and frequencies for the structure. This data is then reformatted and (quite differently from a SAP4 response spectrum analysis) processed so that only the most significant modes are used. When the dynamic response is obtained, a file which contains the mass that did not participate in the response is also written. This mass file is then used to perform a static analysis to capture high frequency response. The dynamic and high frequency responses are then combined in a standard SRSS manner. The inclusion of the high frequency response was previously not available but was implemented as recommended to the NRC. The MODSAP procedure for the SRSS combination of modal results was used as per the recommendations although it is now thought that CQC combination may give better results.

D. Campbell, G. Tirsell, and W. Laird, *Improved 50-ps Rise Time X-Ray Detector with Optical Applications*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86340 (1981). Prepared for the 23rd Annual Meeting of the American Physical Soc., Division of Plasma Physics, New York, NY, October 12-16, 1981.

We have improved the impulse response characteristics of the LLNL 50 ps detector significantly. The detector has also been improved mechanically to permit much greater ease of assembly and repair. We are investigating modified versions of this design for optical applications. The detector was developed to complement the recording capability of our Thomson-CSF 4 GHz oscilloscopes in laser-driven ICF fusion experiments research.

G.A. Carlson, W.L. Barr, B.M. Boghosian, R.S. Devoto, J.N. Doggett, G.W. Hamilton, B.M.

*With Physical Acoustics Corporation, Sacramento, CA 95813.

Johnston, W.N. Kumai, J.D. Lee, B.G. Logan, R.W. Moir, W.S. Neef, and R.B. Campbell,* *Comparative End-Plug Study for Tandem Mirror Reactors*, Lawrence Livermore National Laboratory, Livermore, CA, UCID-19271 (1981).

We have completed a comparative evaluation of several end plug configurations for tandem mirror fusion reactors with thermal barriers. The axicell configuration has been selected for further study and will be the basis for a detailed conceptual design study to be carried out over the next two years. The axicell end plug has a simple mirror cell produced by two circular coils followed by a transition coil and a Yin-Yang pair, which provides for MHD stability.

D.N. Cornish, R.W. Hoard, and R. Baldi,† *Design of 12-T Yin-Yang Magnets Operating in Subcooled Superfluid Helium*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-85957 (1981). Prepared for the 9th Symp. on Engineering Problems of Fusion Research, Chicago, IL, October 26-29, 1981.

A conceptual design study of a large 12-T Yin-Yang pair of coils, typical of the plug coils envisioned for a tandem-mirror facility to follow MFTF, has been completed. Because of its larger size and field strength, the magnetic forces are much greater than those experienced on MFTF. The main purpose of this study, therefore, is to assess the feasibility of such a device, paying particular attention to mechanical stress and conductor strain.

The conductor proposed operates at 15.6 kA and consists of a rectangular half-hard copper stabilizer with a Nb-Ti insert in the low-field regions and Nb₃Sn in the high field. The coil is divided into four sections in the longitudinal direction, with steel substructure to limit the winding stress to an acceptable level. The conductor is cryostatically stabilized in superfluid He at 1.8 K and 1.2 atm, with an operating heat flux of $0.8 \text{ W} \cdot \text{cm}^{-2}$.

We conclude that the building of such a magnet system should be possible with modest extensions to present-day technologies.

Dale H. Darling, Thomas P. Bernat, and Brent H. Ives, *Wavelength Dependence and Efficiency of Laser Heating of DT-Filled Polymer Coated Glass Microspheres at Cryogenic Temperatures*, Lawrence

Livermore National Laboratory, Livermore, CA, UCRL-86158 (1981). Prepared for the 28th Natl. American Vacuum Soc. Symp., Anaheim, CA, November 2-6, 1981.

The utility of using a heating laser to vaporize the solid DT fill in the heat-pulse fast-refreeze method for production of uniform solid DT layers inside polymer coated glass microsphere targets, as well as the susceptibility of such cryogenic targets to driving laser ASE depends critically on the amount of incident laser energy absorbed by the target. The relative absorption efficiency may vary with target material (polymer, glass, and solid DT layers) as well as the wavelength of the illuminating laser.

We have determined experimentally the fraction of laser light incident on DT-filled cryogenic polymer coated and bare glass microsphere targets that is absorbed to produce target heating. Data has been obtained for bare glass and CH and CF polymer coated microspheres at 488 and 632 nm laser wavelengths.

The measurement technique used and experimental results obtained will be presented.

B.S. Denhoy, *Vacuum System for Advanced Test Accelerator*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86190 (1981). Prepared for the 28th National Symp., American Vacuum Soc., Anaheim, CA, November 3-6, 1981.

The Advanced Test Accelerator (ATA) is a pulsed linear electron accelerator designed to study charged particle beam propagation. The ATA is designed to produce a 10 000-A, 50-MeV, 70-ns electron beam. The electron beam acceleration is accomplished in ferrite loaded cells. Each cell is capable of maintaining a 70-ns 250-kV voltage pulse across a 1-in. gap.

The electron beam is contained in a 5-in.-diam, 300-ft-long tube. Cryopumps, turbomolecular pumps, and mechanical pumps are used to maintain a base pressure of 2×10^{-6} Torr in the beam tube. The accelerator will be installed in an underground tunnel. Due to the radiation environment in the tunnel, the controlling and monitoring of the vacuum equipment, pressures, and temperatures will be done from the control room through a computer interface.

This paper describes the vacuum system design, the type of vacuum pumps specified, the reasons behind the selection of the pumps and the techniques used for computer interfacing.

*With TRW, Inc., Redondo Beach, CA.

†With General Dynamics, Convair Division, San Diego, CA.

J.W. Dini, *Electrodeposition—A Viable Coating Alternative*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87144 (1982). Prepared for the Intern. Conf. on Metallurgical Coatings and Process Technology, San Diego, CA, April 4-9, 1982.

This paper reviews the metals and alloys which can be produced by electrodeposition. Then, using copper as an example, the wide variation of properties that can be obtained with one metal are discussed.

J.W. Dini and H.R. Johnson, "Plating on Some Difficult-to-Plate Metals and Alloys," *Plating and Surface Finishing* 68, 64 (October 1981).

Electrodeposition of coatings on metals such as beryllium, beryllium-copper, Kovar, magnesium, thorium, titanium, tungsten, uranium, zirconium, and their alloys can be problematic. This is due, in most cases, to a natural oxide surface film that readily re-forms after being removed. The plating procedures outlined in this report rely on replacing the oxide film with a displacement coating, or etching to allow mechanical keying between the substrate and plated deposit. The effectiveness of the procedures is demonstrated by interface bond strength determined by ring-shear and conical-head tensile tests.

J.W. Dini and H.R. Johnson, *Quantitative Adhesion Data for Electroless Nickel Deposited on Various Substrates*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86807 (1981). Prepared for Proc. 2nd AES Symp. on Plating on Difficult-to-Plate Materials, St. Louis, MO, March 25, 1982.

This paper includes a review of the literature on quantitative adhesion of electroless nickel deposited on a variety of substrates. Procedures for obtaining good adhesion between electroless nickel coatings and a variety of aluminum alloys (1100, 2024, 5083, 6061, and 7075), beryllium-copper, and 4340 steel are outlined.

J.N. Doggett, *Studies for a Fusion Technology Development Facility*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86972 (1982). Prepared for the Conf. on Fast, Thermal, and Fusion Reactor Experiments, Salt Lake City, UT, April 12-15, 1982.

We have been studying small, driven fusion reactors as candidates for a Technology Development Facility (TDF) to be used for testing reactor

subsystems, components, and materials. Magnetic mirror systems are particularly interesting for this application because of their inherent steady-state operation, potentially high wall loading, and relatively small size. The stimulus for this work was the 1974 Fusion Engineering Research Facility (FERF) Study at Lawrence Livermore National Laboratory (LLNL), along with the increased emphasis on technology development in the United States National Fusion Program.

The systems so far studied have 14-MeV neutron wall loads ranging from 1 to 3 MW·m⁻² on testing surface areas of 2 to 5 m² with annual fluences as high as 10²¹ neutrons·cm⁻². These devices are based on physics and engineering that has been demonstrated or is scheduled for demonstration in the next year.

Our first approach was to look at a machine with a single central plasma reacting cell and two auxiliary cells, which provide improved confinement and plasma stability. This machine, with 18 MW of fusion power, produces an average first wall flux of 1.5×10^{14} neutrons·cm⁻²·s⁻¹ over 1.8 m² of test space, while consuming 125 MW of utility power. This machine uses technology that is in hand, or to be demonstrated this year, and on tandem-mirror-barrier physics that will be demonstrated in late 1982.

The second machine we are studying is a tandem mirror machine employing strong stabilization like the Tandem Mirror Experiment (TMX), but with improved performance provided by the introduction of a set of unyielded, high-field, solenoid magnets to enhance plasma confinement. This tandem version produces a fusion power of about 15 MW, yielding a uniform wall load of 0.5×10^{14} neutrons·cm⁻²·s⁻¹ on an area of 5.5 m² with an input power at about 250 MW.

This type of device has an excellent potential for developing and demonstrating fusion reactor technology at an early date and at minimum cost.

R.R. Donaldson, S.R. Patterson, and D.C. Thompson, *Diamond Machining and Mechanical Inspection of Optical Components*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86897 (1981). Prepared for Brookhaven Conf. on Synchrotron Radiation—High Resolution Soft X-Ray Optics, November 18-20, 1981.

Displacement measurement and motion control are discussed for rotary and linear axes of motion, as necessary for the dimensional measurement and diamond-tool machining of grazing incidence x-ray optics. Examples of available performance levels are drawn from measurements

made on current developmental hardware, and are coupled with speculation on possible future extensions.

P.F. Durbin, G.H. Armstrong, and A. Kuramoto, *Microcomputer-Based Ultrasonic Inspection of Solder Bonds in Superconducting Cable*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87598 (1982). Prepared for *Materials Evaluation*, journal of the American Society for Nondestructive Testing.

A real-time microcomputer-based, ultrasonic inspection system has been developed in the course of building the Mirror Fusion Test Facility at the Lawrence Livermore National Laboratory. This inspection system is designed to evaluate solder bonding in superconducting cable before it is wound onto magnets that will help confine the fusion reaction. A five-transducer water cell and related ultrasonic equipment sends output to a high speed data acquisition system, and a real-time data analysis program checks the cable for flaws and reports damage to a teletypewriter. The system is designed for stand-alone operation, and will function in harsh industrial environments.

D.M. Egle,* C.A. Tatro, and A.E. Brown, *Frequency Spectra of Acoustic Emission from Nodular Cast Iron*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86461. Prepared for *Materials Evaluation*, American Soc. for Nondestructive Testing.

Experiments to determine the normalized energy spectral density of signals emanating from two different sources of acoustic emission in nodular cast iron are described. The energy spectra are computed from digitized transient acoustic emission (AE) signals and smoothed to reduce the errors caused by the randomness of the location of the AE source. Energy spectra of signals associated with dislocation mechanisms show significant differences compared to spectra of those caused by particulate cracking.

W.W. Feng, *On Finite Deformation of Elastic and Viscoelastic Disks under Rotation*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87567 (1982). Prepared for the 2nd European Symp. on Flywheel Energy Storage, Torino, Italy, May 9-14, 1983.

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The governing equations for a class of axisymmetric problems, under large elastic or viscoelastic deformations, are formulated in terms of two coupled first-order ordinary differential equations with explicit derivatives. This class of problems concerns a circular disk with rotational body force as well as nonuniform initial thickness. Materials with a neo-Hookean strain-energy function are used for elastic formulation. The constitutive equations developed by Christensen are used for viscoelastic formulation. A recurrent formula for the hereditary integrals is obtained. This recurrent formula makes it possible for the same governing equations and numerical methods to be applied to both elastic and viscoelastic problems.

W.W. Feng, *On Three-Dimensional Thick Composite Shells*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87223 (1981). Prepared for the 11th Southeastern Conf. on Theoretical and Applied Mechanics, Huntsville, AL, April 8-9, 1982.

The solutions to three-dimensional composite shells are obtained. The undeformed configuration of the shells is assumed to have an axis of symmetry; therefore, it is governed by two independent variables. The loading can be axisymmetric or asymmetric; therefore, there are three dependent unknown functions for three components of the displacement vector. These unknown functions are determined by the minimum potential energy principle.

The results of several examples are presented in this article. The profile of the deformed shells and the calculated displacement vector are compared with the experimental data.

The strength of the thick composite shells is studied. The results are compared with the acoustic emissions signals from the shells during loading.

Dennis K. Fisher and James N. Doggett, *Mechanical Engineering Aspects of Mirror Fusion Technology*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87347 (1982). Prepared for the American Soc. of Mechanical Engineers Annual Winter Meeting, Phoenix, AZ, November 14-19, 1982.

The Mirror approach to magnetic fusion has evolved from the original simple mirror cell to today's main line efforts, the tandem mirror machine with thermal barriers. Concurrent with the physics development have been steady advances

in the engineering technology supporting the experimental plasma physics research. As mirror fusion approaches net power production, many significant engineering challenges lie ahead.

Mirror fusion research is being pursued throughout the world. At the University of Tsukuba, Japan, the GAMMA-10 tandem mirror machine employing axisymmetric mirror coils is under construction. At the Lawrence Livermore National Laboratory, the Tandem Mirror Experiment (TMX) Upgrade incorporating thermal barriers and radio frequency plasma heating has just become operational. Also at Livermore, the largest of the mirror machines, the Mirror Fusion Test Facility (MFTF), has completed successful engineering tests of its prototypical superconducting Yin-Yang magnet set, cryogenic, vacuum, and computer control systems. Completion of this machine, designed to achieve equivalent Q 's of 0.5 to 1.0, is scheduled for 1985. Other major efforts in the U.S. include the TARA experiment at MIT, the PHAEDRUS experiment at the University of Wisconsin, and the Symmetric Tandem Mirror at TRW. Additional mirror fusion experiments are in various stages of design and construction in West Germany and the USSR.

The U.S. mirror program calls for the construction of several major devices on the way to commercial power. The Tandem Mirror Next Step (TMNS), slated for start of construction in the mid 1980s, will be a D-T burning device with an ignited central cell. Its principal purpose will be to demonstrate the engineering feasibility of the tandem mirror reactor. The Tandem Mirror Demonstration Reactor (TMDR), scheduled for the 1990s, is conceived as a full scale reactor which will provide data for the design and construction of reliable commercial power reactors in the 21st century. Concurrent with TMNS and TMDR is the need for the advancement of the supporting engineering technologies. The Technology Demonstration Facility (TDF), a small, driven mirror fusion reactor, is proposed as a device for developing and demonstrating reliable engineering reactor subsystems, components, and materials.

In order to achieve the programmatic milestones described, substantial advances are needed in a number of supporting engineering technologies. Several of these are specific to the mirror program. In the area of magnetics, superconducting solenoidal magnets with peak fields of up to 15 T over a bore of 0.5 m may be needed for the TMDR. Continuous duty vacuum systems capable of high rate pumping of a combination of DT and He will be required to maintain the necessary

pressure conditions. In the area of plasma heating, the mirror program projects the need for high energy (approximately 200 keV, 50 A) continuous duty neutral beam sources, as well as high power (multimegawatt) radio frequency plasma heating systems. Direct conversion, a technique for efficiently converting a flux of charged particles to electricity, must be further developed to handle the multimegawatt/m² thermal loads of reactor plasma and ion dumps. Other technological needs are generic to the fusion program. For example, safe and reliable methods for handling tritium in a reactor environment must be demonstrated, as well as techniques for remotely maintaining neutron-activated reactor components. Finally, substantial progress is needed in developing and qualifying materials for reliable use in the high fluxes of 14 MeV neutrons characteristic of fusion reactors.

The mirror fusion program has made several orders of magnitude improvement in demonstrated performance in the past five years. We are rapidly approaching the point where engineering technology, rather than plasma physics, will become the critical path to commercial fusion power. Mechanical engineers will play key roles in the areas of magnetics, vacuum, plasma heating/fueling, and reactor product handling systems.

D. N. Frank and N. Milleron,* *Automobile Flywheel Energy Storage: Practical Vacuum Requirements*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86822 (1981). Prepared for the 28th National Symp., American Vacuum Soc., Anaheim, CA, November 2-6, 1981.

For passenger automobiles with 1367 kg curb weight during typical driving conditions in city traffic, fuel efficiency improvements between 50-100% (5-7 km/hr) can be realized by proper utilization of a flywheel-energy storage unit (0.2 kWh) and a heat engine. A brief introduction is given concerning the pros and cons of flywheels compared to other energy storage options. Discussion is then given regarding a serious concern of composite-flywheel energy storage for vehicles: that of a suitable vacuum environment for the rotating, composite flywheel. To be practical, a vacuum system for such an environment must be reliable, safe, and economical (in energy resources and dollars) to manufacture, monitor, maintain, and repair. Each embodiment of flywheel energy

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storage may be sufficiently unique to require a vacuum environment tailored to suit it. A general discussion of the important vacuum parameters and practical vacuum systems is followed by examples of candidate designs.

L.L. George, *Super Mann-Whitney Simulation of System Reliability*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL 86221. Prepared for the Winter Simulation Conf., San Diego, CA, December 6-8, 1982.

Component reliability is the probability of component survival. Component survival can be modeled as occurring when load is less than strength. System reliability is the probability of survival of subsets of components. A fault tree specifies which subsets are required for survival. System reliability is modeled this way in the Seismic Safety Margins Research Program.

System reliability computation is difficult because:

1. There are many components.
2. There are many subsets whose survival causes system survival.
3. Loads and strengths are dependent among themselves and on each other.

System reliability simulation is an alternative, but simulation requires a large number of simulation runs if component reliabilities are high. Mann-Whitney simulation requires far fewer simulation runs. It re-uses every one of the n^2 combinations of simulated loads and strengths to estimate system reliability. Super Mann-Whitney simulation is the same as Mann-Whitney simulation except that it uses all combinations of load-strength pairs.

For example, suppose there are $m = 2$ components, $n = 2$ loads and strengths for each component, and $n^2 = 4$ load-strength pairs for each component. There are $n^{2m} = 16$ pairs of pairs, and each yields a distinct system state, survival or failure. Check each component to see whether its load X is less than its strength Y , then check to see whether subsets of components required for system survival have loads less than strengths. If so, count one more survival.

The proportion of survivals in all simulation runs is a system reliability estimator. For simple simulation of n independent runs with h survivals, the estimator is h/n . For Mann-Whitney simulation of n^2 runs with i survivals, the estimator is i/n^2 . For super Mann-Whitney simulation of n^{2m} runs with j survivals, the estimator is $j/(n^{2m})$.

Every estimator should be accompanied by an indication of its accuracy. Variance of the pro-

portion estimator indicates the accuracy of the system reliability estimator. For simple simulation, the variance of the proportion is estimated by $h(n - h)/n^3$. For Mann-Whitney simulation, the variance of the proportion is derived from the variance of the Mann-Whitney test statistic, $n^2(2n + 1)/12$ when the loads and strengths have the same distribution functions except for a location parameter. For super Mann-Whitney simulation, the variance of the proportion is estimated by a jackknife estimator. The jackknife requires computing the proportion estimator n times where each computation is based on $n - 1$ runs. The variance estimator is a function of the n proportions.

Confidence intervals on system reliability can be estimated from the distribution function of the proportion of survivals. The exact distribution of the Mann-Whitney test statistic can be computed for small n . The asymptotic distribution for large n is normal. For super Mann-Whitney simulation, the distribution of the proportion depends on the definition of system survival. The distribution can be approximated using extreme value theory of dependent random variables for series or parallel systems.

R. Godwin, C. Hurley, E. Wallerstein, K. Whiteman, J.E. Murray, E. Bliss, R. Ozarski, M. Summers, D. Gritton, F. Holloway, G. Suski, J. Severyn, and F. Rienecker, *Engineering Design of the Nova Laser Facility for Inertial Confinement Fusion*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87444 (1981). Prepared for the 9th Symp. on Engineering Problems of Fusion Research, Chicago, IL, October 26-29, 1981.

The design of the Nova laser facility for inertial confinement fusion experiments at Lawrence Livermore National Laboratory is presented from an engineering perspective. Emphasis is placed upon design-to-performance requirements as they impact the various subsystems that comprise this complex experimental facility.

Alfred Goldberg, James E. Hanafee, and Robert G. Scott, *Mechanical Properties Evaluation of Some Questionable Beryllium Material*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87392 (1982). Prepared for JOWOG 22, Golden, CO, April 19-20, 1982.

We evaluated the integrity of a beryllium component that had developed questionable etching patterns on chemical milling. The tensile properties of the questionable material, which

was vacuum hot-pressed Be (VHP), and this material after an additional hot isostatic pressing (VHP/HIP) were compared to two (baseline) Be materials that were considered acceptable. Tensile testing was performed under strain-rate control conditions at 10^{-4} and 2×10^{-2} /s at -22, 22, and 55°C. We found that the tensile properties of all four materials fell within specifications and there were no obvious differences in their ductilities. However, differences in strength values were obtained. In addition, yield drops were observed for the baseline materials, while the VHP and VHP/HIP materials showed only a slight delay in strain hardening following initial yielding. Both the yield drop and delayed strain hardening were more pronounced with an increase in temperature.

Metallographic examination revealed that specimens of relatively low ductility showed "chevron-like" markings flowing from a single origin. Such markings were virtually absent in the more ductile specimens. The lower ductility specimens were also associated with relatively larger concentrations of "fines" at crack initiation sites on the fracture surface. As expected, segregation of microvoids and/or inclusions was present in the VHP questionable material. However, fracture paths did not necessarily favor such segregated regions, a behavior which is consistent with the absence of any significant difference in ductility between the four materials.

J. Goldhar, M.W. Taylor, and J.R. Murray, *Characterization of an Efficient High Gain Raman Amplifier*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86889 (1982). Prepared for the Conf. on Lasers and Electro-Optics, Phoenix, AZ, April 14-16, 1982.

A Raman amplifier using methane gas and KrF laser pump was investigated. Gain, saturation characteristics, and thresholds for parasitics were experimentally measured and compared to a theoretical model. High conversion efficiency, pulse compression, and brightness enhancement were demonstrated.

M.A. Hamstad, *Acceptance Testing of Graphite/Epoxy Composite Parts with Acoustic Emission*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86649 (1981). Prepared for NDT International.

A graphite/epoxy composite dome is proof-tested by pressurization. Acoustic emission (AE) data is obtained during the proof test. A low-

frequency bandpass is used to minimize AE signal propagation losses. The AE system and test part are calibrated *in situ* by an instrumented pencil-lead break. Large energy AE signals provide a clear indication of a flawed composite part.

M.A. Hamstad, R. Wells,* and A.K. Mukherjee,* *On the Origin of the First Peak of Acoustic Emission in 7075 Aluminum Alloy*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86751 (1981). Prepared for the *Journal of Materials Science*.

The origin of acoustic emission (AE) in 7075 aluminum alloy was investigated in tension and compression tests. It is suggested that the first peak associated with the root-mean-square (rms) AE plot vs time (or strain) is due to unpinning of dislocation segments from solute atom clusters and is not due to fracture of particles. Alteration in the value of the AE first peak and also in electrical resistivity values due to heat treatment of this alloy support the proposed origin of the AE first peak near yield.

Arthur R. Harvey, *Analysis and Design of Short, Iron-Free Dipole Magnets*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86966 (1981). Prepared for the 9th Symp. on Engineering Problems of Fusion Research, Chicago, IL, October 26-29, 1981.

Iron-free, dipole magnets are used extensively as steering magnets to correct for the bending, induced by extraneous magnetic fields, of particle beams that are being transported in vacuum. Generally, the dipoles are long enough that the space occupied by the end conductors is small compared to the overall magnet length. In a recent application, however, this criteria did not apply. This has motivated a reanalysis of the characteristics of a system of small aspect ratio (length/diameter) dipoles that are spaced at relatively large axial distances. The following observations and conclusions resulted from this analysis:

1. The effective magnet length is a simple function of the axial conductor lengths, their relative orientation, and their magnet diameter.
2. The overall magnet strength is a function of axially parallel conductors only.
3. End conductors should be placed in a single plane normal to the axis at each end of the magnet.

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4. Flat wound and formed magnets lead to considerable cost reductions over more conventional winding methods.

5. Increasing the number of turns yields more favorable power supply matching, better field uniformity, and more favorable heat dissipation.

6. Increasing the number of end conductors and upturning them provides a more favorable field profile at the ends of the magnet.

The above points are discussed in this report. Some fabrication techniques which are being developed in a prototype magnet are also discussed.

P. Paul Hed, *Laser Rod Holder During Grinding and Polishing*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87076 (1982). Prepared for *Applied Optics* 21, No. 9, 1539 (1982).

The conventional way of holding a single laser rod during optical surfacing of its end faces is to cement the rod with thermoplastic material into a hole in a metal block. This method, which requires heat, is both slow and may even crack the rod. To overcome these, a clamping holder was designed. It is made of a cylinder, a plastic bushing, and tightening screws.

R.W. Hoard, D.N. Cornish, R.W. Baldi,* and W.D. Taylor,* *Utilizing Subcooled, Superfluid He-II in the Design of a 12-Tesla Tandem Mirror Experiment*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86326 (1981). Prepared for the Workshop on the Stability of Superconductors in He-I and He-II, Saclay, France, November 16-19, 1981.

A design study of 12-T Yin-Yang coils for a conceptual Tandem Mirror Next Step (TMNS) facility has been recently performed by Lawrence Livermore National Laboratory in conjunction with the Convair Division of General Dynamics. The large magnets have major and minor radii of 3.7 and 1.5 m, 0.70×3.75 m² cross section, 46.3 MA turns, and an overall current density of 1763 A/cm², obtained by the use of Nb₃Sn and Nb-Ti superconductors. Each coil is composed of several subcoils separated by internal strengthening substructure to react the enormous electromagnetic forces. The size of the Yin-Yang coils, and hence the current density, was reduced by utilizing subcooled, superfluid HE-II at 1.8 K for the coolant. This paper reviews the design study, with empha-

sis on He-II heat transport and conductor stability. Methods are also presented which allow the extension of Gorter-Mellink-channel calculations to encompass multiple, interconnecting coolant channels.

Jack Hovingh, *Performance Requirements of an Inertial Fusion Energy Source for Hydrogen Production*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87498 (1982). Prepared for the 12th Symp. on Fusion Technology, Julich, West Germany, September 13-17, 1982.

The production of hydrogen as a relatively nonpolluting fuel for industry and transportation may be necessary in the long-term future. We are investigating the use of inertial fusion as the energy source for a hydrogen production plant.

Performance of an inertial fusion system for the production of hydrogen is compared to a tandem mirror system hydrogen producer. Both systems use the GA sulfur-iodine hydrogen production cycle and produce no net electric power to the grid. The performance parameter for the inertial fusion reactor driven hydrogen production plant is the fusion energy gain $\eta_D Q$ where η_D is the laser efficiency and Q is the pellet gain. An inertial fusion driven hydrogen producer will have a higher ratio of the heat rate of hydrogen production to the fusion reactor circulating electric power requirements than the design point for the tandem mirror system with a fusion energy gain of 6.9 if the inertial fusion $\eta_D Q$ is greater than 8.8. However, for the inertial fusion to have a higher ratio of the heat rate of hydrogen production to the fusion power than the tandem mirror will require an inertial fusion $\eta_D Q$ greater than 17.

Three examples of the requirements for an inertial fusion energy source for a hydrogen production plant producing 5.8 kg-moles/s of H₂ were considered. For a fusion energy gain $\eta_D Q$ of 8.8 and a given laser efficiency of 7%, the pellet gain Q required is 126. The minimum driver energy for a "best estimate" gain of 126 is 4 MJ. The pulse repetition frequency required is 11 Hz. Reducing the laser efficiency to 4.4% will require a pellet gain of 220. The minimum driver energy for a "best estimate" gain of 220 is 10 MJ with a prf of 2.5 Hz. For a fusion energy gain of 17, and a driver efficiency of 7%, the required pellet gain is 240. Using a 10-MJ driver will require that the pellet performance slightly exceed the "best-estimate" gain.

An inertial fusion energy source utilizing realistic pellet and laser performances can compete

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in terms of system performance with the tandem mirror energy source for producing hydrogen.

C.A. Hurley, G. Bradley, F. Frick, C. McKee, M. Demos, G. Lee, B. Gim, J. Braucht, A. Martos, D. Watts, and H. Julien,* *Nova Mechanical Systems*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86008. Prepared for the 9th Symp. on Engineering Problems of Fusion Research, Chicago, IL, October 26-29, 1981.

The mechanical subsystem of the Nova project is responsible for the mechanical design of laser components, structural design of stable supports, design of auxiliary equipment, and their integration into the total system. A Nova beam line consists of a series of amplifier stages from 5-cm aperture to 46-cm aperture. In series with amplifiers, are spatial filters, optical isolation equipment and turning mirrors. The output aperture of each of the 10 beams is 74 cm.

This paper will discuss the design features of these components, their stable support, fabrication, assembly, cooling, and operational intricacies.

The sensitivity of optical systems requires that particulate contamination be minimized. Particles on optical surfaces result in surface damage, when exposed to flashlamp or laser light. Consequently, in design, one must consider engineering options that do not generate contaminants. Maintaining cleanliness in operation is done by rigid control of cooling gas, beam line enclosures and maintenance procedures. To ensure high system performance each feature must allow for fast, easy, clean and efficient maintenance.

To hit small targets, components and supports must be designed for high stability. Dynamic motions are limited to less than $\pm 3.0 \mu\text{m}$. Thermal motion is limited by air temperature control, which is $\pm 0.5^\circ\text{C}$ in a maximum period of 15 minutes.

Support for components is provided by the spacecraft. It is designed to be stiff, yet free to expand if thermal control is disrupted. It must withstand seismic loadings. Lenses and mirrors are mounted in manipulators and gimbals that permit accurate alignment and stability working against vacuum loads.

B.C. Johnson, J.B. Bryan, M.E. Murray, M.A. Summers, J.D. Williams, and B.W. Woods, *Development and Optical Performance of Large Aperture Harmonic Generation Crystal Arrays*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86907 (1981). Prepared for the Conf. on Lasers and Electro-Optics, Phoenix, AZ, April 14-16 (1982).

A 3-by-3 matrix of precision-oriented, diamond-machined 5-by-5-cm KDP crystals has closely matched single-crystal performance in prototyping the large-aperture arrays required for frequency converging LLNL's Nova laser.

W.K. Kelley, W.C. Cowden, and G.E. Overturf, *Electroforming Cylindrical Parts with Precision Small Inside Diameter Pinholes*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87224 (1981). Prepared for *Metals and Plastics*.

The pinhole, which is the heart of the Electronic Pinex Image Neutron Experiment, is a diagnostic tool used to measure the shape of neutron emitting sources. Prior to this work there were primarily two methods for fabricating these pinholes: (1) by electrically discharge machining (EDM), and (2) by conventionally drilling wafer inserts 0.125-in. thick and stacking to the required length. We present an electroforming technique which involves plating a neutron attenuating metal onto a tube then dissolving out the tube to produce a part of the required length without stacking. Development of the electroforming process and results obtained are described in this paper.

W.K. Kelley, J.W. Dini, and C.M. Logan, "Electroforming Copper Targets for RTNS-II," *Plating and Surface Finishing* 69, 54 (March 1982).

Copper targets used in RTNS-II, the world's most intense 14-MeV neutron source, contain water-cooling channels for temperature control. There are two methods for fabricating these targets: (1) diffusion bonding a copper panel containing photoetched channels to another copper panel, and (2) an electroforming technique that involves filling the photoetched channels with wax, plating thick copper to seal over the channels, and removing the wax. Development of the latter process and results obtained with it are described in this paper.

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T.A. Kozman, Y. Chang, E.N.C. Dalder, C.L. Hanson, R.E. Hinkle, J.A. Horvath, C.R. Montaya, D. Ng, E.O. Owen, B. Palasek, D.W. Skinner, J.H. VanSant, S.T. Wang, J.H. Berkey, R.S. Cone, R.E. Patrick, and P.N. Tirapelle, *Testing of the MFTF Magnets*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87506 (1982). Prepared for the 9th Intern. Cryogenic Engineering Conf., Port Island, Kobe, Japan, May 11-14, 1982.

This paper describes the cooldown and testing of the first Yin-Yang magnet for the Mirror Fusion Test Facility. The introduction describes the superconducting magnet and, the rest of the paper explains the tests prior to and including magnet cooldown and final acceptance testing. The MFTF (originally MX) was proposed in 1976 and the project was funded for construction start in October 1977. Construction of the first large superconducting magnet set was completed in May 1981 and testing started shortly thereafter. The acceptance test procedures were reviewed in May 1981 and the cooldown and final acceptance test were done by the end of February 1982. During this acceptance testing the magnet achieved its full design current and field.

Satish V. Kulkarni and Alan J. Hannibal,* *Fabrication of High Performance, Filament-Wound Composite Rings*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87286 (1982). Prepared for the 14th National Soc. for the Advancement of Materials and Process Engineers Technical Conf., Atlanta, GA, October 12-14, 1982.

During the past several years, many different flywheel designs made from composite materials were evaluated as potential candidates for commercial service in the future. The development of most of these concepts was funded by the Department of Energy. Of these, only two remain in the DOE program: a high energy density multi-rim design, and a modest energy density, less expensive ring-on-disk design. For the latter, the disk is a 52-glass/epoxy laminate and the ring is a carbon/epoxy circumferentially wound ring. The ring is fitted over the disk by first shrinking the disk in liquid nitrogen.

This paper deals with the ring-on-disk configuration, particularly the fabrication and associ-

ated problems of the carbon/epoxy ring. Specifically, the following issues are presented. The winding process for rings having a thick annular section is discussed in some detail, both for a rectangular and a tapered cross section. The purpose of the tapered cross section is to reduce the radial tensile stress. The calculated residual stresses induced by the manufacturing processes are compared with measured results. Residual stresses in the range of 7000 to 10000 psi were observed. The effect of silicone carbide whiskers on the transverse strength and transverse modulus of carbon/epoxy composites is discussed. The experimental data was measured from specimens taken from filament-wound flat panels. The impact of SiC reinforcement on the performance of a ring-on-disk flywheel is presented.

C.S. Landram, *Measurement of Fusion Boundary Energy Transport During Arc Welding*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87277 (1982). Prepared for the ASME Journal of Heat Transfer.

An experimental technique is presented to identify fusion boundary (liquid/solid interface) energy transport mechanisms during welding procedures. The gas-tungsten-arc spot-welding procedure, using a low melting point specimen material (lead), was chosen to demonstrate the methods. Vaporization energy losses were found to be important during the growth of the fusion boundary. Significant thermal convection was absent within the weld pool for applied currents less than about 100 A, and for such cases the location of the fusion boundary was found to be governed primarily by heat conduction. At the current levels of almost 300 A, significant weld pool convection was found to exist, especially at the (inner) stagnation point, causing a deeper penetration of the fusion boundary there.

C.S. Landram, W.H. McMaster, and E.Y. Gong, *Steam Chugging Calculations with the PELE-IC Code*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86207 (1981). Prepared for the Journal of Nuclear Engineering Design.

Vapor region collapse mechanisms during chugging in Boiling Water Reactor (BWR) pressure suppression systems are identified by the role of condensation in locally destabilizing the vapor-liquid interface in the vicinity of the submerged tube exit. Vapor collapse is shown to be further hastened by complete vapor separation from the

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end of the tube. Equivalent adiabatic vapor systems are shown to exhibit stable gas-liquid interfaces and therefore have no tendencies for collapse.

J.D. Lee, *The Fusion Breeder: Its Potential Role and Prospects*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86995 (1981). Prepared for the Proc. of the Intern. Workshop on Nuclear Energy Evolution, sponsored by the Intern. Institute for Applied System Analysis, Schloss Laxenburg, Austria, May 25-27, 1981.

The fusion breeder is a concept that utilizes 14-MeV neutrons from $D + T \rightarrow n(14.1 \text{ MeV}) + \alpha(3.5 \text{ MeV})$ fusion reactions to produce more fuel than the tritium (T) needed to sustain the fusion process. This excess fuel production capacity is used to produce fissile material (^{239}Pu or ^{251}U) for subsequent use in fission reactors. We are concentrating on a class of blankets we call fission suppressed. The blanket is the region surrounding the fusion plasma in which fusion neutrons interact to produce fuel and heat.

The fission-suppressed blanket uses non-fission reactions [mainly $(n,2n)$ or $(n,n't)$] to generate excess neutrons for the production of net fuel. This is in contrast to the fast fission class of blankets which use (n,fiss) reactions to generate excess neutrons. Fusion reactors with fast fission blankets are commonly known as fusion-fission hybrids because they combine fusion and fission in the same device.

J.D. Lee, R.W. Moir, W.L. Barr, R.S. Devoto, G.W. Hamilton, and W.S. Neef (all LLNL); D.H. Berwald, J.A. Maniscalco, W.D. Bjorndahl, R.B. Campbell, J.K. Garner, J. Ogren, R.H. Whitley, N. Ghoniem, and M. Youseff (all with TRW, Inc., Redondo Beach, CA; K.R. Schultz, E.T. Cheng, R.L. Creedon, I. Maya, P.W. Trester, C.P.C. Wong (all with General Atomic Co., San Diego, CA); R.P. Rose, D.L. Chapin, J.W.H. Chi, and J.S. Karbowski (all with Westinghouse Electric Corp., Pittsburgh, PA; and W.R. Grimes (ORNL), *Feasibility Study of Fission-Suppressed Tandem Mirror Hybrid Reactor*, Lawrence Livermore National Laboratory, Livermore, CA, UCID-19327 (1982).

Results of a conceptual design study of a ^{233}U producing fusion breeder consisting of a tandem mirror fusion device and two types of fission-suppressed blankets are presented. The majority of the study was devoted to the conceptual design

and evaluation of the two blankets. However, studies in the areas of fusion engineering, reactor safety, fuel reprocessing, other fuel cycle issues, economics, and deployment were also performed.

The first blanket studied uses an inner zone of depleted lithium for tritium breeding and cooling, with an outer zone containing molten salt for fissile breeding and cooling. This concept features on-line lithium and molten-salt fuel processing. Neutrons in excess of that needed for tritium breeding are available for fissile breeding by virtue of the $^7\text{Li}(n,n't)$ reaction. The second blanket studied uses beryllium for neutron multiplication, a LiPb suspension of ThO_2 for tritium and ^{233}U breeding, helium for cooling, and features aqueous (thorex) fuel reprocessing. The beryllium resource, while possibly too limited for extensive pure fusion application, will be adequate (with carefully planned industrial expansion) for the fusion breeder application because of the large support ratio; hence few fusion breeders required. Fabrication and radiation damage of beryllium remain issues to be resolved by further study and experimentation.

Molten salt reprocessing economics were compared to aqueous reprocessing (thorex). The predicted cost (levelized) for molten-salt reprocessing is \$1.9/g fissile, whereas the aqueous reprocessing cost estimate is \$23/g fissile for thorium metal and 28 to 42 \$/g fissile for ThO_2 . Molten salt handling and processing appear to be attractive but require more development.

The fusion driver for these fusion breeders is a 3000-MW axicell tandem mirror operating in the thermal barrier mode with 20-T barrier coils. The Li- and Be-based blankets are predicted to produce 4.5 and 6.6 tonnes/y of ^{233}U , respectively, in addition to the tritium required to fuel the DT fusion reactions. When used as makeup to conventional light water reactors (LWRs), 15 GW and 22 GW of electric power can be supported. Both fission-suppressed blankets are predicted to be significantly safer than fission systems by virtue of much lower radioisotope inventories and afterheat. Initial studies indicate that both blankets have very low probability of radioactivity release.

The electricity generation cost from fusion-fission systems consisting of these fusion breeders and conventional LWRs being supplied make fuel is predicted to be 13% and 8.9% above that of an LWR fueled with mined uranium. A \$100/kg U_3O_8 fuel cost, 3% real U_3O_8 cost escalation, and full fissile recycle in the LWR, is assumed. The electrical output from the breeders accounts for only 8%

and 5% of total system output. The cost of bred fissile material (^{235}U), expressed as an equivalent U_3O_8 cost, was \$91/lb for the Li case with molten-salt reprocessing and \$76/lb for the beryllium case with aqueous reprocessing.

In 1982 we plan to pursue a relatively low technology hybrid which uses beryllium and thorium (or uranium) pebbles cooled by liquid lithium with equivalent U_3O_8 costs expected to be \$75/lb or less. At a lower level we plan to pursue a higher technology hybrid which uses beryllium and molten salt with an equivalent U_3O_8 cost of \$60/lb. All costs are in 1980 dollars. These results are based on the hybrid costing approximately 3.5 times a light water reactor for the same nuclear power. Advances which lower the cost of the fusion reactor will lower the cost of fissile material produced.

High support ratio results in attractive deployment scenarios. Only a relatively small number of fusion breeders are needed to support a large-scale fission economy. In a specific fusion breeder/LWR deployment example, only 81 fusion breeders would be required to support the LWR nuclear capacity required to meet 50% of U.S. electrical demand (1600-GWe nuclear) in the year 2050. If LWRs and LMFBs are included in the fission reactor mix, only 40 fusion breeders would be required.

P.H.Y. Lee, K.G. Tirsell, G.R. Leipelt, and W.B. Baird, *Measurement of 2-5 keV X-Ray Emission from Laser-Target Interactions by Using Fluor-MCP and CsI-XRD Detectors*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86306 (1981). Prepared for the 23rd Annual Meeting of the American Physical Soc., Division of Plasma Physics, New York, NY, October 12-16, 1981.

For inertial confinement fusion plasma diagnostics, x-ray diode (XRD) detectors using conventional cathodes are not sensitive enough to measure x rays above ~ 1.5 keV. However, for laser driver fusion targets, x rays in the range of 2-5 keV are important because of their mobility in the target. We have successfully used fluor-microchannel plate (MCP) detectors to obtain absolute x-ray measurements in the 2-5 keV range. Recent data obtained from experiments on the Shiva laser system are presented. In addition, designs for a variety of channels in the range using fluor-MCP and CsI-XRD's above 1.5 keV will be discussed.

Donald R. Lesuer, *Methodology for Studying Tank Track Pad Failures*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87393 (1982). Prepared for the U.S. Army Tank-Automotive Command, Troy, MI, March 29-30, 1982.

Lawrence Livermore National Laboratory in conjunction with the U.S. Army Tank-Automotive Command has developed a methodology for studying the tank track pad failure problem. Our means of studying this problem are centered around computer modeling and laboratory experiments. The computer modeling studies are based upon the finite element method and evaluate a cross section of tank track. Two models have been developed—one that studies the temperature buildup in pads, while the other studies the mechanical response of the pads to the operation of the vehicle. The models provide a key link between laboratory tests and expected field response. The laboratory tests interface with the analysis work in two different ways. The first is by providing material data input to the computer codes. The second is by evaluating the material resistance to failure given the temperature and stress levels of operation provided by the models. Material and design changes can be studied in a relatively inexpensive and straightforward manner using this methodology. This approach can also provide input on the critical material properties and their values for use in an engineering specification. We will present results for both the T142 and T156 track.

D.R. Lesuer, R.H. Cornell, and S.D. Santor, *Cyclic-Stress-Strain Behavior of Rubber*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86688 (1982). Prepared for the 1982 Joint Conf. on Experimental Mechanics of the Soc. for Experimental Stress Analysis, Honolulu, HI, May 22-30, 1982.

Rubber in general exhibits nonlinear viscoelastic behavior. One manifestation of this nonlinearity is a variation in the dynamic moduli with strain amplitude. However, a closer examination of the dependence of dynamic moduli on strain suggests that for engineering problems, a linear viscoelastic treatment may provide an adequate representation of the constitutive behavior of rubber, provided the moduli are evaluated at the strain range and loading frequency of interest. This presentation describes an experimental study

into the suitability and limitations of a simple linear viscoelastic model used in several large deformation finite element computer codes. The procedure was to obtain the cyclic stress-strain behavior of a rubber suitable for use in a load bearing application and compare the results with the stress-strain response predicted by the finite-element code NIKE2D. This code was developed at Lawrence Livermore National Laboratory to study the finite strain response of solids subjected to axisymmetric or plane strain deformation.

G.J. Linford, R.A. Haas, E.T. Marchi, W.W. Simmons, and M.A. Summers, *Apodization of Large Aperture Nova Laser Harmonic Conversion Crystal Arrays*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86906 (1982). Prepared for the Conf. on Lasers and Electro-Optics, Phoenix, AZ, April 14-16, 1982.

Experimental and theoretical investigations have resulted in the development of an effective apodizing technique for eliminating adverse diffraction effects produced by the interstitial obscurations in large-aperture (74 cm) Nova laser harmonic conversion crystal arrays.

B.W. Maxfield and R.D. Weglein,* *An Acoustic Microscope for Surface Characterization*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86767 (1981). Prepared for Proc. 1981 Ultrasonics Symp., Chicago.

Acoustic microscopy has been used recently for nondestructive thickness measurements of surface layers. The approach is based upon the thickness-dependence of the surface wave velocity in a layered medium. Using an acoustic material signature from a focused beam microscope as described in the literature, one can determine the surface-wave velocity. This technique also has the potential of providing information on coating defects and surface adhesion. An experimental facility is being established at LLNL for the characterization of the relatively thick coatings that are protecting surfaces from corrosion and erosion. Thicknesses in the range of 0.01 to 0.25 mm require an operating frequency between 5 and 200 MHz. An experimental system capable of operation at discrete frequencies between these limits has been constructed and initially used to obtain the acoustic material signature of aluminum on beryllium from which we deduce the surface wave velocity. This measured velocity compares favorably with calculated results.

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W. McLean, C.A. Colmenares, R.L. Smith, and G.A. Somorjai,* *The Chemisorption of CO and CO₂ on Gold Supported ThO₂ Films*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86251 (1982). Prepared for the *Journal of Physical Chemistry*.

The chemisorption of CO and CO₂ on gold-supported ThO₂ films has been studied by x-ray photoelectron spectroscopy (XPS). At pressures $\sim 10^{-5}$ Pa both gases were found to adsorb molecularly at room temperature. The ThO₂ films were prepared by drying and calcining a Th(NO₃)₃-ThO₂ slurry which was painted onto a gold substrate. Films prepared in this manner were mechanically and chemically stable, and were characterized by Auger electron spectroscopy (AES), XPS, x-ray diffraction, and scanning electron microscopy (SEM). Comparison of known and calculated stoichiometries has led us to propose a new atomic sensitivity factor (ASF) for the Th(4f_{7/2}) photoelectron peak.

W. McLean, C.A. Colmenares, R.L. Smith, and G.A. Somorjai,* *Electron-Spectroscopy Studies of Clean Thorium and Uranium Surfaces. Chemisorption and Initial Stages of Reaction with O₂, CO, and CO₂*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86167. Prepared for *Phys. Rev. B* 25, No. 1 (1982).

The adsorption of O₂, CO, and CO₂ on the thorium (111) crystal face and on polycrystalline α -uranium has been investigated by x-ray photoelectron spectroscopy, Auger electron spectroscopy (AES), and secondary-ion mass spectroscopy (SIMS) at 300 K. Oxygen adsorption on both metals resulted in the formation of the metal dioxide. CO and CO₂ adsorption on Th(111) produced species derived from atomic carbon and oxygen; the presence of molecular CO was also detected. Only atomic carbon and oxygen were observed on uranium. Elemental depth profiles by AES and SIMS indicated that the carbon produced by the dissociation of CO or CO₂ diffused into the bulk of the metals to form a carbide, while the oxygen remained on their surfaces as an oxide.

R.W. Mensing and L.L. George, *Upper Probability Limits on Failure Probabilities when Parameters are Uncertain*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86213 (1981). Prepared for the Low Probability, High Consequence Risk Analysis Workshop, Washington, DC, June 15-17, 1982.

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In probability risk analysis, one important risk measure is the probability of failure of components and systems. If S is the strength at failure of a component and R is the response of a component subject to stress (due to normal operation, external forces such as earthquakes and winds), a component will fail if $R > S$. To represent inherent randomness, R and S are random variables. To measure risk, we must estimate $P(R > S)$. If the distributions of R and S are known, $P(R > S)$ is a deterministic value. However, the distributions of R and S are usually unknown so $P(R > S)$ must be estimated. This paper derives an upper limit for $P(R > S)$ when the parameters of the distributions of R and S are uncertain and this uncertainty is represented by a probability distribution for the parameters. For instance, the distribution may be the sampling distribution of parameter estimators. It may be a subjective distribution that expresses lack of knowledge about the parameters. The estimated upper limit is an upper probability limit on $P(R > S)$.

This paper derives an upper probability limit for $P[\phi(Z) < 0]$ where the event $\phi(Z) < 0$ is failure of a system, $\phi(\cdot)$ is the structure function of the system, Z is a random vector of the form $Z = R - S$, and R and S are the response and strength vectors of the components in the system. The joint distribution, $G(\theta)$, of the parameters, θ , of the distribution of Z is assumed. The method is to maximize

$$P[\phi(Z) < 0; \theta]$$

subject to

$$1 \geq G(\theta) \geq 1 - \alpha$$

as a function of θ . The constrained maximum of $P[\phi(Z) < 0; \theta]$ is an upper $1 - \alpha$ probability limit.

For a single component the probability limit for $P[\phi(Z) < 0; \theta] = P(R > S)$ is derived when only the means, μ_R and μ_S , are uncertain. Optimization is not required. The derivation is extended to multiple, correlated vectors R and S .

When more than the location parameters are uncertain, the probability limit for $P(R > S)$ is the solution to the mathematical programming problem defined above. The explicit solution is derived when R and S are independent normal or lognormal random variables and the unknown parameters are independent and uniformly distributed.

R.W. Mensing and L.L. George, Using Subjective Percentiles to Quantify Uncertainty and Estimate

Correlation of Fragility Functions, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86224. Prepared for the U.S. Department of Energy Statistical Symp., Idaho Falls, ID, Oct. 13-15, 1982.

The objectives are to estimate:

1. The cdf's (fragility functions) of strengths of failures.
2. The joint cdf's of fragility function parameters.
3. The correlations between strengths at failures.

These estimates help estimate failure probabilities in the Seismic Safety Margins Research Program.

The data are subjective percentiles of fragility functions, percentiles of the percentiles, and percentiles of conditional fragility functions. They are obtained by an expert opinion questionnaire available from the authors. The questionnaire has a nominal fragility function representing inherent randomness and two other cdf's that are subjective confidence limits of specified size on the nominal fragility function. The experts give subjective percentiles of the three cdf's and identify the units of strength. The data for estimating correlation are the subjective percentiles of conditional fragility functions given the strength at failure of another component.

The fragility function parameters are estimated by least squares from the percentiles of the nominal fragility function. The joint cdf of the parameters is estimated by bounding the parameters and unconditioning the bounds. The correlation is estimated by least squares from the conditional percentiles. Additional estimates of the fragility function parameters are obtained by least squares from the conditional percentiles. These additional estimates are compared with the other estimates to determine expert consistency.

The nominal fragility function is assumed to be a normal or lognormal cdf. Two test statistics, a sum of squared errors and a pseudo likelihood ratio, indicate which cdf is more likely. The subjective confidence limit cdf's are assumed to pass through the 10th and 90th percentiles of the uncertain mean strength at failure. The conditional fragility functions are also assumed to be normal or lognormal. Therefore, the conditional percentiles are functions of correlation which allow correlation to be estimated.

The joint cdf of uncertain mean and variance is estimated as follows. Conditional on a value of the upper 90th percentile on the mean, the variance is bounded below by the smaller variance of

the cdf's that pass through the 90th percentiles on the other subjective percentiles of the nominal fragility function. Conditional on a value of the lower percentile on the mean, the variance is bounded above by the larger variance of the cdf's that pass through the 10th percentiles on the other subjective percentiles on the nominal fragility function. Unconditioning according to an assumed cdf for the uncertain mean yields the joint cdf of mean and variance.

Correlations and additional estimates of the nominal mean and variance are obtained as follows. Percentiles of the conditional fragility functions are functions of the nominal mean, variance, and correlation and of the condition. We minimize the sum of squares of the differences between the conditional percentiles and the experts' opinions as a function of nominal mean, variance, and correlation. The sum is over all experts, percentiles, and conditions.

Michael J. Murphy, *An Improved Design for Dynamically Loaded, Threaded Interfaces*. Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86739 (1982). Prepared for the Symp. on Advances and Trends in Structural and Solid Mechanics, Washington, DC, October 1982.

An improved thread design for dynamically loaded, threaded interfaces is presented. Maximum stress is generally located in the thread relief region or the root of the first thread of a threaded interface under load. Consequently, a nonuniform stress distribution exists throughout the thread. The improved thread design presented in this paper provides for an alternate load path resulting in a uniform stress distribution and elimination of the thread root and relief stress concentration. Whitworth and ACME type threads have been examined using hydrodynamic finite-element analysis techniques. Correlation with experimental results is good. The new thread design has been successfully implemented in the high explosive velocity augmented kinetic energy penetrator.

William S. Neef, Jr., *Some New Ideas for Tandem Mirror Blankets*. Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86793 (1981). Prepared for the 9th Symp. on Engineering Problems of Fusion Research, IEEE, Chicago, IL, October 26-29, 1981.

The Tandem Mirror Reactor, with its cylindrical central cell, has led to numerous blanket designs taking advantage of the simple geometry. Also many new applications for fusion neutrons

are now being considered. To the pure fusion electricity producers and hybrids producing fissile fuel, we are adding studies of synthetic fuel producers and fission-suppressed hybrids.

The three blanket concepts presented are new ideas and should be considered illustrative of the breadth of Livermore's application studies. They are not meant to imply fully analyzed designs.

J.L. Opsal, *Recent Developments in Diffraction Theory and Their Effect on the Design of Ultrasonic Inspection Systems*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87099 (1981). Prepared for SPIE's 25th Annual Intern. Tech. Symp. and Exhibit, San Diego, CA, August 24-28, 1981.

Significant recent developments in elastic wave scattering theory are discussed in terms of their effect on the use of ultrasonics for quantitative flaw characterization in structural materials. The discussion begins with an introduction on nondestructive evaluation (NDE) describing the need for a quantitative ultrasonics technology that includes a knowledge of the fundamental ultrasound-flaw interaction and the ability to apply that knowledge in practice. Our present level of understanding is then illustrated using several examples of theoretical results for both direct and inverse scattering problems. Very little mathematical detail is employed in the discussion with the emphasis placed, rather, on graphically displaying results and showing differing effects for different scatterers. Concluding the discussion is a description of a new, sophisticated ultrasonic test instrument, an ultrasonic test bed, under construction at the Lawrence Livermore National Laboratory. This facility, when completed, will allow for the testing and practical implementation of existing and emerging advanced ultrasonic concepts such as described here.

John Opsal and Allan Rosencwaig, *Thermal-Wave Depth-Profiling: Theory*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86544 (1981). Prepared for the *Journal of Applied Physics*.

We have developed a one-dimensional model for thermal-wave depth-profiling that provides expressions for the temperature at the surface of the sample and for the thermoelastic response beneath the surface. The model shows that elastic wave interference effects produce significant differences between samples with mechanically free and constrained surfaces, and that thermal-wave

images of thermal conductivity variations are obtainable from the thermoelastic signal only if the front surface is mechanically free. We have also considered the case of subsurface heating and found that for heating occurring at depths of more than a few thermal diffusion lengths, the thermoelastic signal becomes independent of thermal conductivity variations. This has important implications for thermal-wave image range and resolution.

G.D. Poe and J.L. Opsal, *Application of Parameter Estimation/System Identification to Quantitative Ultrasonic NDE*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87098 (1981). Prepared for the DARPA/AF Review of Progress in Quantitative NDE, Boulder, CO, August 2-7, 1981.

The use of ultrasonics for the quantitative characterization of flaws in materials generally requires some method of extracting useful information from the scattered ultrasonic wave assuming that the time variation of the incident wave is known. We have developed a solution to this type of problem within the framework of parameter estimation and system identification. In our approach, a solution within a prescribed set of possible solutions is sought such that an L_2 -norm is minimized. The form of the norm is such that it indicates a measure of similarity between the experimental observation and the possible solutions within the prescribed set. The basis of this approach and several examples will be presented.

R.H. Reiss, *A Four Position Indexing Evaporation Shutter*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87083 (1982). Prepared for Review of Scientific Instruments.

The vacuum deposition of four different materials in one pumpdown to a thickness of 1000 nm (100 Å) each required a special fixture that would index four specific witness flats used for measurement and calibration of the deposited materials. The purpose of this note is to describe the indexing fixture.

F. Rienecker, Jr., J.E. Field, J.D. Williams, M.A. Summers, M.S. Singh, J.R. Severyn, J.F. Kane, R.A. Dickinson, and E.A. Barna*, *Nova Target Systems*, Lawrence Livermore National Labora-

tory, Livermore, CA, UCRL-86014. Prepared for the 9th Symp. on Engineering Problems of Fusion Research, Chicago, IL, October 26-29, 1981.

The Nova beam focusing arrangement consists of two opposing clusters, each comprising 5 (or 10) beams positioned uniformly in angle upon the surface of a 100° cone whose vertex is at the target. ICF targets must be supported in a high vacuum, and precisely located in space. The laser beams can be focused onto the target in a variety of geometries; in addition, laser pulses must arrive simultaneously in time and space. The wavelength will be varied to one-half and one-third of the fundamental by nonlinear crystals, which must be precisely oriented with respect to the fundamental laser beam. All of these motions are remotely controlled and instrumented. All components of the system are both massive, and delicate, requiring careful fixture design for fabrication, testing, and handling. Neutron activation of components influences materials selection and personnel safety considerations.

Performance of the target is diagnosed in terms of x-ray spectrum vs time, shape of x-ray source, energy absorbed reflected and scattered, and charged particles and neutrons produced.

This paper describes the mechanical aspects of designs for the Nova target chamber vacuum system, lens positioners, target alignment optics, plasma diagnostics and integrated controls and instrumentation.

James H. Rose* and J.L. Opsal, *Inversion of Ultrasonic Scattering Data*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87006 (1981). Prepared for: Proc. DARPA/AFML Review of Quantitative NDE, Boulder, CO, 1981.

The elastic wave inverse scattering problem is examined from the point of view of the Inverse Born Approximation (IBA). We show that the IBA yields highly accurate results for the shape of complex composite voids given sufficient scattering data. The IBA is shown to provide accurate determinations for the size and shape of simple cracks and for a composite flaw which consists of a void with a circumferential crack. The Born Approximation is also shown to provide a means for determining the composition of inclusions.

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G.M. Sanger, *Some Thoughts on the Role of Electroplated Coatings in Optics and Some Considerations for Their Production*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87084 (1982). Prepared for the American Electroplaters' Soc. SUR/FIN '82, San Francisco, CA, June 20-24, 1982.

New and exotic applications of optics to directed energy weapons systems, advanced astrophysical, and alternative energy applications, to name a few, are forcing reconsideration of the available optical materials and manufacturing processes. Metal and coated metal optics of both conventional and unconventional geometry are of particular importance in these areas due to their unique efficiency and optimal functional properties. The emerging importance of these coated metal optics will be discussed, including the types and characteristics of coatings required, the optical design process and a very short survey of the more common and important applications. Also, a perspective on the optical manufacturing technologies and their implications to the characteristics of the plated coatings is given. Finally, a short survey describing the size of the potential market for coated optics in the next decade will be presented.

G.M. Sanger and J.W. Dini, *A Perspective on Electrodeposited and Electroless Nickel Coatings Used in Optical Applications*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87058 (1982). Prepared for the American Electroplaters' Soc. SUR/FIN '82, San Francisco, CA, June 20-24, 1982.

Electrodeposits of copper, gold, silver, and electroless nickel coatings are playing an ever more important role in optical technology. Any material that can be adherently coated with these deposits can be finished by conventional polishing or diamond turning techniques, thus greatly expanding design strategies and supporting manufacturing capability for optical surfaces. The importance of good quality coatings, e.g., the absence of surface pits, porosity, nodules, stress, and inclusions large enough to damage the diamond tool or adversely effect conventional polishing processes are emphasized and information is presented on influence of plating defects on optics. Recent data on the diamond turning and polishing of other electrodeposited coatings including bright nickel, sulfamate nickel, and tin-nickel are also included.

R.G. Scott and J.C. Stone, *The Effects of Design Variables on the Critical Stresses of Eye Bars Under*

Load: An Evaluation by Photoelastic Modeling, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-85805 (1982). Prepared for the 1982 Joint Conf. on Experimental Mechanics of the Soc. for Experimental Stress Analysis, Honolulu, HI, May 22-30, 1982.

Textbooks on machine design and relevant handbooks have not approached in depth the problem of estimating the effects of major design variables on the critical stresses in the eye-bars used for heavy lifting. This paper reports the critical stresses determined experimentally by the photoelastic modeling of design variations of geometry and pin clearance with and without a bushing between the pin and the lug. Experimental data are compared to values developed from theoretical analysis.

A.F. Shakal and R.C. Murray, *Earthquake Strong-Motion Instrumentation at Lawrence Livermore National Laboratory*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-53246 (1981).

A network of strong-motion accelerographs has been installed at the Lawrence Livermore National Laboratory as part of the LLNL Site Seismic Safety Program. The network has two objectives: (1) to provide quantitative information on the severity of ground shaking for the assessment of structural effects at LLNL following an earthquake, and (2) to provide data for analyses of the free-field ground motion and the causative earthquake. The network includes digital multichannel central-recording systems in Building 111 (9-channel) and in Building 332 (18-channel). Independent analog accelerographs are included to provide redundancy. A multichannel system has also been installed on the spaceframe at the Laser facility. In addition to the structural instrumentation, six free-field stations are located at and near the Laboratory. The strong-motion network will provide rapid indication of peak ground-motion values as well as data for detailed post-earthquake studies of ground motion and structural response.

A.B. Shapiro and R. Gressmann, *Aluminum/Cuprous Oxide Thermite*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-53189 (1982).

"Thermite" is a generic name applied to a class of metal-metal oxide reactants that undergo a chemical oxidation reduction reaction with the liberation of large amounts of thermal energy. If a mixture of aluminum and cuprous oxide is ignited, the thermite reaction

will proceed at such a rapid rate (burn rate of 6 cm/s) and with the evolution of so much heat (580 cal/g) that the temperature will rise to about 2570°C.

The thermite reaction, accordingly, has been used for sabotaging or destroying military equipment, starting military fires, and welding together large sections of metal. Aluminum/cuprous oxide (Al/Cu₂O) thermite is discussed in this report with respect to these topics:

- Reactant powder characterization.
- Powder contaminant extraction.
- Reactant powder compaction into a consolidated pellet.
- Initiation system.
- Reaction and reaction product analysis.

C.G. Stevens, N.J. Wessman, J.E. Bowman, and W.J. Ramsey, *Photolysis of Water Vapor on Titanium/TiO₂ Surfaces*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87310 (1982). Prepared for *Chemical Physics Letters*.

The photolysis of water vapor on the surface of titanium-coated polycrystalline n-TiO₂ at a temperature of 380°C is reported. A quantum conversion efficiency for hydrogen production of 2 percent is measured for excitation above the band gap of TiO₂. The experiments demonstrate the catalytic nature of the reaction with respect to the active material and also suggest an important role played by the titanium metal in the observations.

S.E. Stokowski, W.H. Lowdermilk, F.T. Marchi, J.E. Swain, E.P. Wallerstein, and G.R. Wirtenson, *Advances in Optical Materials for Large-Aperture Lasers*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86656 (1981). Prepared for *Electro-Optics/Laser '81*, Anaheim, CA, November 17-19, 1981.

Lawrence Livermore National Laboratory (LLNL) is using large-aperture Nd:glass lasers to investigate the feasibility of inertial confinement fusion. In our experiments high power laser light is focused into a small (100-500-μm) target containing a deuterium-tritium fuel mixture. During the short (1 to 5 ns) laser pulse the fuel is compressed and heated, resulting in fusion reactions. The generation and control of the powerful laser pulses for these experiments is a challenging scientific and engineering task, which requires the development of new optical materials, fabrication techniques, and coatings. With considerable co-

operation and support from the optical industry, where most of the research and development and almost all the manufacturing is done, LLNL has successfully applied several new developments in these areas.

The newest version of high power lasers for fusion research is the 20-beam Nova laser, of which 10 beams are now under construction. The output aperture of Nova is 74 cm, considerably larger than any previous system, including the 20-beam Shiva laser with its aperture of 20 cm. Nova will generate approximately 200-300 kJ of energy in 3 ns at 1053-nm wavelength. Using frequency conversion in a nonlinear material, it will provide 120-200 kJ at 527 nm and 100-180 kJ at 351 nm for our fusion experiments. The following statistics indicate the massiveness of the Nova project:

Optics for the Nova laser (20 beams)

2000 major optical components

4000 l of laser glass

2000 l of fused silica

20,000 l of borosilicate glass

300 l of crystals

400 m² of optical quality surfaces

200 m² of optical thin film coating

1.1 m maximum diameter

380 kg maximum weight

3×10^9 W/cm² at 1 ns average flux

0.06 μm average optical surface accuracy.

In obtaining optics for Nova, we had to consider the large scale-up in size, the high laser flux (twice as high as previous laser systems) to which they would be exposed, and the multiple wavelength operation. At the same time we had to maintain good optical quality, high laser damage resistance, and low cost. We discuss how our laser glass, mirrors, lenses, KDP crystals (the wavelength converter), and filters meet these stringent requirements placed on them.

Irving F. Stowers and George Batchelder,* *Collection of Pollen and Spore Samples in the Livermore Valley from February 1981 to July 1982*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87262 (1982). Prepared for the 6th Intern. Symp. on Contamination Control, Tokyo, Japan, September 13, 14, 16, 1982.

Pollen and spores were collected over an 18-mo period in the Livermore Valley of California to determine their rate of infiltration into buildings with varying air handling systems. The samples

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were collected using Rotorod samplers in both an outdoor location and at six indoor locations. The building air filtration systems included 30, 65 and 95% ASHRA efficient filters and 99.995% high efficiency particulate air (HEPA) filters. Up to 50 types of pollens and spores were identified and counted on a weekly schedule, then sorted and plotted to determine indoor versus outdoor concentration ratios. The general results show that indoor concentrations were approximately 0.01 of outdoor concentrations independent of filtration type or general air handling system characteristics. The one exception was a room containing HEPA filters where indoor concentrations were even lower when compared to the conventionally filtered rooms. The indoor concentrations generally followed (were proportional to) the outdoor concentrations throughout a pollen of spore season.

R.D. Streit, *Design Guidance for Fracture-Critical Components at Lawrence Livermore National Laboratory*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-53254 (1982).

Fracture is an important design consideration for components whose sudden and catastrophic failure could result in a serious accident. Elements of fracture control and fracture mechanics design methods are reviewed. Design requirements, which are based on the consequences of fracture of a given component, are subsequently developed. Five categories of consequences are defined. Category I is the lowest risk, and relatively lenient design requirements are employed. Category V has the highest potential for injury, release of hazardous material, and damage. Correspondingly, the design requirements for these components are the most stringent. Environmental, loading, and material factors that can affect fracture safety are also discussed.

R.D. Streit, *Development of a Simple Biaxial-Strain Test*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87237 (1982). Prepared for the 1982 Joint Conf. on Experimental Mechanics of the Soc. for Experimental Stress Analysis, Honolulu, HI, May 22-30, 1982.

Materials which obey a maximum tensile stress failure criteria can fail at strains in biaxial tension which are significantly below the uniaxial failure strain. First, a failure strain envelope is developed which accounts for the degree of biaxiality and the work hardening of the material. A material test which would account for the vari-

ous states of biaxiality is then proposed. By deforming a flat plate into a prescribed surface, different states of biaxial strain can be achieved. The development of such a biaxial test as a cost-effective and reliable means of screening certain materials is presented. The test is compatible with most drop weight test facilities and can be used to screen materials over a wide variety of temperature and strain rates.

M.A. Summers, L.G. Seppala, F. Rienecker, D. Eimerl, and B.C. Johnson, *Nova Frequency Conversion System*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86009 (1981). Prepared for the 9th Symp. on Engineering Problems of Fusion Research, Chicago, IL, October 26-29, 1981.

Frequency conversion of Nd:glass lasers by harmonic generation is routinely used for generating intense visible and ultraviolet light. In this article, we describe our plans for implementation of harmonic generation on the Nova laser. The basic concept, scaling to large aperture, and integration with the alignment and diagnostic systems are discussed. In addition, the multiwavelength target focusing system is described.

S.B. Sutton, *The Effect of a Two-Dimensional Obstacle on the Dispersion of a Heavier-Than-Air Gas in an Atmospheric Boundary Layer*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-53288 (1982).

The results of a combined numerical and experimental investigation of the effect of a two-dimensional obstacle on the dispersion of a heavier-than-air gas in an atmospheric boundary layer are presented.

In the numerical analysis portion, the governing equations are developed and the numerical solution algorithm is discussed. Fluid motion was governed by the two-dimensional, incompressible Navier-Stokes equations and the equations for mass conservation. The two-equation Jones-Lauder turbulence model was used to provide closure of the Reynolds stresses and fluxes. Curvature correction and pressure gradient models were incorporated in the turbulence equations. An implicit algorithm, employing the ADI technique of Peaceman and Rachford was used for the parabolic equations. The elliptic pressure equation was solved using a direct matrix solution method.

In the experimental portion, a rough wall boundary layer that simulated an atmospheric surface layer flow was generated in a 21.3-m long

wind tunnel having a cross section of 1.18 by 1.68 m at the test section. Measurements were made at a free-stream velocity of 2.4 m/s for an obstacle size of 0.076 m. The obstacle Reynolds number was 5339.

Profiles of the mean velocity and turbulent kinetic energy are presented for 10 longitudinal positions from 5 obstacle lengths upstream to 12 obstacle lengths downstream of the leading edge of the obstacle. Results of a numerical simulation of the wind tunnel measurements are given showing the effect of turbulence model changes on the numerical solution and its comparison with measurements. Concentration results are presented for numerical simulations of dispersion in an atmospheric flow at an obstacle Reynolds number of 3.36×10^6 , showing the effect of gas density, injection source location, and turbulence model changes on the cloud formation.

Clement A. Tatro, *Acoustic Emission in Nondestructive Evaluation*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87449 (1982). Prepared as a chapter for the *Encyclopedia of Materials Science and Engineering* (Pergamon Press).

General information concerning acoustic emission applications to nondestructive evaluation is presented. The origins of acoustic emission in solid materials are described. Observations that can be made using a piezoelectric sensor attached to the surface of a test part are discussed, as are common methods of data analysis and recording. Unique features of acoustic emission as a nondestructive evaluation method are described, along with a discussion of the advantages and disadvantages of the method.

C.A. Tatro, A.E. Brown, and S.J. Vahaviolos*, *Investigation of Acoustic Emission Response from Laser Welds, Phase I*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86899 (1981). Prepared for the 23rd AEWG Meeting, Toronto, Canada, December 1-3, 1981; also submitted to *Welding Journal*.

Initial attempts to correlate acoustic emission (AE) response to the quality of a YAG pulsed laser edge weld in stainless steel will be reported. The AE record will be related to a video taped reproduction of the weld surface, magnified 120 times by means of a fiber optics microscope.

M.W. Taylor, J. Goldhar, and J.R. Murray, *Dylux: an instant image photographic material suitable for UV laser beam diagnostics*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86474. Prepared for *Applied Optics* 21, No. 1, (1982).

The Du Pont Corp. Photo Products Department manufactures an instant image, dry process photographic proofing material for the graphic arts industry which we have found to be a very useful tool for beam diagnostics in experiments using UV lasers. The material, sold under the trade name Dylux, develops a continuous-tone blue dye image when exposed to radiation at wavelengths shorter than ~ 400 nm. The material can be rendered insensitive to further UV exposure by fixing the image with an intense exposure to visible light. The exposure required to deactivate the material is sufficiently large that unexposed material can be handled for several minutes under normal laboratory illumination without significant change in sensitivity, and the handling period can be extended to several hours if the room lighting is subdued. The material is available in paper form as Dylux 503-1 Instant Image Proof Paper and in film form as Dylux 608 Registration Master Film.

N.L. Thomas, G.R. Wirtenson, W.L. Robinson, and E.F. Wallerstein, *A Scanning Reflection and Transmission Photometer for Large High Power Laser Optics*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86762 (1981). Prepared for the OSA Workshop on Optical Fabrication, Anaheim, CA, December 9-11, 1981.

The Nova Laser Fusion program at Lawrence Livermore National Laboratory requires the use of large optics up to 109-cm diam and 380-kg weight. The optical coatings for these optics consist of anti-reflection, high reflector, polarizing beam-splitter, and partial transmitter coatings. The absolute reflectance, overall transmittance, and uniformity of these coatings are measured with a specialized scanning photometer.

The Nova OTR (overall transmittance/reflectance) photometer operates at 1.064, 528, or 351 nm in order to closely simulate 1st, 2nd and

*With Physical Acoustics Corporation, Sacramento, CA 95813

3rd harmonic frequencies of the Nova fusion laser. The optic is scanned on a large XY carriage while reflectance or transmittance data is taken "on-the-fly." The system is controlled by an LSI 11/23 computer which processes the data and prints out the results in hardcopy form, or stores data on a memory disk. The detectors are temperature controlled to within $\pm 0.01^\circ\text{C}$ which aids in achieving of an absolute accuracy of $\pm 0.1\%$ to $\pm 0.5\%$ of full scale, depending on the operating point. The photometer is capable of scanning a large optic (1 m in diameter) in 20-30 min.

E.P. Wallerstein, P. Baker, N.J. Brown, J. Bryan, W.H. Lowdermilk, E.T. Marchi, L.G. Seppala, S.E. Stokowski, J. Willis, W. Whister, and J. Williams, *Optical Components for the Nova Laser*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86013 (1981). Prepared for the 9th Symp. on Engineering Problems of Fusion Research, Chicago, IL, October 26-29, 1981.

In addition to its other characteristics, the Nova laser fusion facility may well be the largest precision optical project ever undertaken. Moreover, during the course of construction, concurrent research and development has been successfully conducted, and has resulted in significant advances in various technical areas, including manufacturing efficiency. Although assembly of the first two beams of Nova is just commencing, the optical production, including construction of the special facilities required for many of the components, has been underway for over three years, and many phases of the optical manufacturing program for the first 10 beams will be completed within the next two years. On the other hand, new requirements for second and third harmonic generation have created the need to initiate new research and development. This work has been accomplished through the enormous cooperation DOE/LLNL has received from commercial industry on this project. In many cases, industry, where much of the optical component research and development and virtually all of the manufacturing is being done, has made substantial investment of its own funds in facilities, equipment, and research and development, in addition to those supplied by DOE/LLNL.

C.E. Walter, *Inductive Power Transfer for Propulsion: A Status Report*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87108 (1982). Prepared for the 61st Annual Transportation Research Board Meeting, National Research Council, Washington, DC, January 18-22, (1982).

Application of the concept of inductive power transfer to propulsion of buses, automobiles, and trucks can contribute to a quality national transportation system. The concept is basically an air gap transformer which inductively couples the primary in the roadway to the secondary suspended beneath the vehicle. Power is transferred efficiently in this manner and can be used in an electric motor for propulsion. The concept originated nearly 100 years ago, but only recently received attention as a means of providing quality highway transportation with little visual and audible presence, no noxious fumes, and without dedicated use constraints. Implementation of this concept could reduce the present, nearly complete dependence of transportation on petroleum.

Current investigations include a detailed experimental program, evaluation of the impact on electrical utility generating capacity and early applications in transit. Progress has been slowed by federal government funding limitations; future progress will be impeded unless new support is forthcoming.

C.E. Walter, M.K. Kong, and D.J. Mullenhoff, *Route Profile Analysis to Determine Suitability of Electric Postal Delivery Vehicle*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86707 (1981). Prepared for the 32nd IEEE Vehicular Tech. Conf., San Diego, CA, 1982.

An instrumentation system and computer program were developed that allow the U.S. Postal Service to determine which postal routes are suitable for electric delivery vehicles. The instrumentation system provides route data. The route data and electric vehicle characteristics are used in the computer program to calculate vehicle energy and power requirements for the particular route. The performance characteristics of electric vehicles are contained in an input data file to the computer program.

The instrumentation system is designed for use during normal mail delivery with gasoline-powered vehicles. The system is powered by the vehicle battery. Minimum operator interaction and inexpensive maintenance-free sensors are featured in the design. Route grade is determined from a pendulum measurement corrected for vehicle acceleration. Acceleration is determined from a measurement of the distance traveled. The value of road grade obtained in this manner is in excellent agreement with civil survey data. The distance transducer utilizes an electro-optical sensor and a rotating disk driven by the speedometer gear to provide a resolution of 3 mm. A

microprocessor provides timing and data management. Data are recorded on a cassette tape.

The instrumentation system is compact and readily installed or removed in a "survey" delivery vehicle. Calibration requirements are minimal. Since postal delivery routes are closed, i.e., they begin and end at the same location (elevation), the bias error in initial orientation of the pendulum can be reduced to zero during data reduction. After the tape is inserted by the operator at the beginning of a run, and identification information is keyed in, data are automatically recorded in 50-s blocks. If the vehicle is not in motion during a data block period, no data are recorded for that period.

Route data on the cassette tape are reduced in subrouting CARAIN which converts the binary data to engineering plots of time, speed, acceleration, road grade, and elevation vs distance. The program CARA determines whether a specific electric vehicle can complete the route, subject to energy and power limitations. Output plots of battery power and battery state of charge vs time are provided. If battery power or motor torque limitations are exceeded, this fact is noted, but otherwise disregarded, as the calculation proceeds to the end of the route or to a set minimum value of battery state of charge. Battery state of charge is determined by a first-order-system method developed at Purdue University; the results compare well with battery test data. CARA was validated by comparing performance predictions with test data obtained with electric postal delivery vehicles. Acceptance test results indicate that a useful route profile analysis system has been developed.

S.-T. Wang, *Stability and Disturbance of Large DC Superconducting Magnets*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86806 (1981). Prepared for the Superconducting Magnet Cryostability Workshop for Helium I and Helium II, CEN/Saclay, France, November 16-19, 1981.

This paper will address the stability aspects of several dc superconducting magnets such as large bubble chamber magnets, detector magnets, and magnets for the Mirror Fusion Test Facility and MHD research facility. Specifically, it will cover the Argonne National Laboratory 12-Foot Bubble Chamber magnets, the 15-Foot Bubble Chamber magnets at Fermi National Accelerator

Laboratory, the Cello thin solenoid at Saclay, the Michigan Cyclotron magnet, the MFTF-B magnet system at Lawrence Livermore National Laboratory, the U-25B Bypass MHD magnet, and the CFFi Superconducting MHD magnet built by Argonne National Laboratory. Discussed in detail are the design constraints, the adopted stability criterion, analyses of stability and disturbance, stability simulation and heat transfer measurements, and the final results of magnet performance.

S.-T. Wang, R. Bulmer, C. Hanson, R. Hinkle, T. Kozman, D. Shimer, R. Tatro,* J. VanSant, and J. Wohlwend,* *The Axicell MFTF-B Superconducting Magnet System*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87563 (1982). Prepared for the 9th Intern. Cryogenic Engineering Conf., Port Island, Kobe, Japan, May 11-14, 1982.

The Axicell MFTF-B magnet system will provide the field environment necessary for tandem mirror plasma physics investigation with thermal barriers. The performance of the device will stimulate DT to achieve energy break-even plasma conditions. Operation will be with deuterium only. There will be 24 superconducting coils consisting of 2 sets of Yin-Yang pairs, 14 central-cell solenoids, 2 sets of axicell mirror-coil pairs, and 2 transition coils between the axicell mirror coil-pairs and Yin-Yang coils. This paper describes the progress in the design and construction of the MFTF-B superconducting magnet system.

J.E. Wells, L.L. George, and G.E. Cummings, *Seismic Safety Margins Research Program: Phase I Final Report—Systems Analysis (Project VII)*. Prepared for the U.S. Nuclear Regulatory Commission by Lawrence Livermore National Laboratory, Livermore, CA, NUREG/CR-2015, Vol. 8, UCRL-53f21, Vol. 8.

This document reports on the Phase I efforts of the Systems Analysis Project to develop the tools and methods for computing the probability of radioactive release from a commercial nuclear power plant in the event of an earthquake. The

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results of the application of these tools and methods to the Zion Nuclear Power Plant Unit 1 are given.

R. Werner and F. Farfaletti-Casali,* *The Clessidra Divertor*, Lawrence Livermore National Laboratory, Livermore, CA. The Clessidra Divertor is patent pending in Italy.

The basic idea of the Clessidra Divertor is to selectively pump the alpha particles (the ash) in a Tokamak reactor, leaving behind for recycle the deuterium and tritium fuel. This differs from "standard" divertors, which must pump all species (D's, T's and α 's) where the α -concentration of the pumped mixture is very low (40 D and 40 T pumped for each α , for example).

To accomplish this selective pumping the Clessidra Divertor uses to advantage two related phenomena:

1. In the generation of divertors for the next experimental power reactors like NET operating in the high edge density regime ($\bar{n}_e = 10^{19}$ to 10^{20} m^{-3}) there is a very high amount of recirculation of particles in the scrape-off zone and in the divertor proper.

2. Helium, as opposed to hydrogen isotopes, does not diffuse through metals and when a surface is bombarded with energetic alphas the alphas are captured in the surface at some depth δ with some capture efficiency η_c and are retained within the material to high fluence ($>10^{22}$ m^{-2}).

Richard W. Werner and Robert G. Hickman, *Producing Thermochemical Hydrogen with the Tandem Mirror Reactor*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87592 (1982). Prepared for the Intersociety Energy Conversion Engineering Conf., Los Angeles, CA, August 8-13, 1982.

Fusion power holds the promise to supply not only electricity but also fuels to meet the balance of our energy needs. A new integrated power and breeding blanket design is described for tandem mirror reactors. The blanket incorporates features that make it suitable for synthetic fuel production. In particular, it is matched to the thermal and electrical power requirements of the General Atomic water-splitting process for production of hydrogen. Some improvements to the high temperature chemical process steps are described.

*Mechanical engineer with the Joint Research Center, Ispra, Italy.

These improvements are expected to allow production of hydrogen at about \$13/GJ wholesale, including financing costs, capital amortization, and profit.

Richard W. Werner, Oscar H. Krikorian, Fred L. Ribe,* Lloyd C. Brown,† Terry R. Galloway, Myron A. Hoffman, Gary L. Johnson, John H. Norman,† Don S. Rowe,†† Shiva Sitaraman,** Gene L. Woodruff,* and T.H. Zerguini,*** *Conceptual Design Study FY 1981: Sunfuels from Fusion—Using the Tandem Mirror Reactor and a Thermochemical Cycle to Produce Hydrogen*, Oscar H. Krikorian, Ed., Lawrence Livermore National Laboratory, Livermore, CA, UCID-19311.

Our study on sunfuels is intended to focus primarily on the engineering aspects of coupling a tandem mirror fusion reactor (TMR) to a thermochemical cycle for the express purpose of producing hydrogen. The hydrogen is then to be used:

- As a portable fuel.
- As a feedstock to synthesize other fuels such as gasoline or methanol.
- To produce other useful hydrocarbons, NH_3 , etc.

The detailed "how to" of hydrogen utilization is beyond the scope of this report and we concentrate solely on the thermochemistry of the basic fuel production process.

The physics data are supportive to the study and are based on the most recent plasma theory and experiment. The model used is that of the tandem mirror reactor with thermal barriers.

C.E. Witherell, "Micro-Brazing with Lasers," *Laser Focus* 17, 11 (1981), pp. 73-80.

Precision metal components are usually joined by melting a filler metal to at least 425°C. A laser can produce such temperatures without the ruinous side-effects of conventional methods.

C.E. Witherell, *Welding Powder Metallurgy Parts*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87090 (1982). Prepared for the *International Journal of Powder Metallurgy and Powder Technology*.

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Welding offers a means for the P/M fabricator to increase markets for his product through broadening the range of attainable shapes, sizes, and alloy combinations. But because of the porosity and heterogeneity characteristic of most P/M structural parts, welding methods commonly used for mill products and castings are often unsuitable. New techniques have been perfected in recent years for joining difficult-to-weld materials and combinations—many of the techniques being spinoffs from energy and aerospace research. A number of these procedures are plausible candidates for relieving the joining problems that have long plagued the P/M industry.

Edward M. Wu, *Estimation of Long-Term Life of Polymeric Composites*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86933 (1981). Prepared for the Soc. of Experimental Stress Analysis/Japan's Soc. of Mechanical Engineers 1982 Joint Conf. on Experimental Mechanics, Honolulu, HI, May 23-30, 1982.

Estimation or prediction of long term life is crucial to the application of composites in high reliability requirements. In the absence of long term data, short term life under higher stress conditions may be extrapolated to long term life under lower service stress conditions. We present an extrapolation method which improves the accuracy of estimation by identifying and maintaining the same failure mechanism in all the time ranges.