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Technical Abstracts

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Preface

This document is a compilation of the published, unclassified abstracts produced by mechanical engineers at Lawrence Livermore National Laboratory (LLNL) during the calendar year 1990.

Many abstracts summarize work completed and published in report form. These are UCRL-JC series documents, which include the full text of articles to be published in journals and of papers to be presented at meetings, and UCID reports, which are informal documents. Not all UCIDs contain abstracts: short summaries were generated when abstracts were not included. Technical Abstracts also provides descriptions of those documents assigned to the UCRL-MI (miscellaneous) category. These are generally viewgraphs or photographs presented at meetings.

The abstracts are arranged by division. There are seven divisions, ARED, ESED, NEED, NTED, WED, ESD, and MFD, that cover the broad range of technologies within Mechanical Engineering. An eighth section contains abstracts written under the aegis of the overall ME Department, some of which were written by authors in other organizations. The next section contains work done under contract for LLNL. The final two sections contain work presented at the ASNT and CUBE conferences. Within each section, abstracts are listed alphanumerically. An author index is provided at the back of this volume for cross referencing.

The publications listed may be obtained by contacting LLNL's TID library or the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161. Further information may be obtained by contacting the author directly.

Contents

Nuclear Test Engineering Division (NTED)

This division is responsible for providing mechanical and civil engineering and technical support to the Laboratory's Nuclear Test Program. The effort includes the design, development, and fielding of complex experiments that support and diagnose the performance and phenomena associated with nuclear explosive tests conducted at the Nevada Test Site. In conjunction with this, the division participates in LLNL research and development activities at the Livermore site.

This division also supports the Nuclear Systems Safety Program in the fields of nuclear reactor safety and nuclear waste material transportation and storage. Other Laboratory programs and organizations supported include the Energy and Resources Program, the Earth Sciences Department, V Division, and Z Division.

UCRL-15910

Design and Evaluation Guidelines for DOE Facilities Subjected to Natural Phenomena Hazards

R. C. Murray *et al.*

The Department of Energy (DOE) and the DOE Natural Phenomena Hazards Panel have developed uniform design and evaluation guidelines for protection against natural phenomena hazards at DOE sites throughout the United States (UCRL-15910). The goal of the guidelines is to assure that DOE facilities can withstand the effects of natural phenomena such as earthquakes, extreme winds, tornadoes, and flooding. The guidelines apply to both new facilities (design) and existing facilities (evaluation, modification, and upgrading). The intended audience is primarily the civil/structural or mechanical engineers conducting the design or evaluation of DOE facilities.

DOE Order 6430.1A, General Design Criteria Manual, was revised in 1989. This current version of Order 6430.1A references these guidelines (UCRL-15910) as an acceptable approach for design evaluation of DOE facilities for the effects of natural phenomena hazards. UCRL-15910 provides earthquake ground acceleration, wind speed, tornado wind speed and other effects, and flood level corresponding to the design basis earthquake (DBE), design basis wind (DBW), design basis tornado (DBT), and design basis flood (DBFL) as described in Order 6430.1A. Integrated with these natural phenomena loadings, UCRL-15910 provides recommended response evaluation methods and acceptance criteria in order to achieve acceptably low probabilities of facility damage due to natural phenomena.

The design and evaluation guidelines presented here control the level of conservatism introduced in the design/evaluation process such that earthquake, wind, and flood hazards are treated on a reasonably consistent and uniform basis. These guidelines also seek to ensure that the level of conservatism in design/evaluation is appropriate for facility characteristics such as importance, cost, and hazards to people on and off site and to the environment. For each natural phenomena hazard covered, these guidelines generally consist of the following:

1. Usage categories and performance goals.
2. Hazard probability from which natural phenomena hazard loading on structures, equipment, and systems is developed.
3. Recommended design and evaluation procedures to evaluate response to hazard loads and criteria to assess whether or not computed response is permissible.

Performance goals are expressed as the annual probability of exceedance of some level of facility damage due to natural phenomena. The appropriate performance goal for a facility is dependent on facility characteristics such as mission dependence, cost, and hazardous functions. Different guidelines are provided for four usage categories—each with a specified performance goal. Usage categories and performance goals range from general use (normal building code provisions) to highly hazardous use (approaching nuclear power plant provisions).

The likelihood of occurrence of natural phenomena hazards at each DOE site has been evaluated by the DOE Natural Phenomena Hazard Program. Probabilistic hazard models are available for earthquake, extreme wind/tornado, and flood. Alternatively, site organizations are encouraged to develop site-specific hazard models.

UCID-21572

Assessment of Seismic Margin Calculation Methods

R. C. Murray

Seismic margin review of nuclear power plants requires that the high confidence of low probability of failure (HCLPF) capacity be calculated for certain components. The candidate methods for calculating the HCLPF capacity recommended by the Expert Panel on Quantification of Seismic Margins are the conservative deterministic failure margin (CDFM) method and the fragility analysis (FA) method. The study (NUREG/CR-5270) evaluated these two methods using some representative components to provide further guidance in conducting seismic margin reviews. It is concluded that either of the two methods could be used for calculating HCLPF capacities. This supplement documents the calculations performed by a selected group of architect engineers on the same components studied in NUREG/CR-5270.

UCID-21830

Determination and Application of Bias Values in the Criticality Evaluation of Storage Cask Designs

W. R. Lloyd

The work described here is the first of three planned tasks in a project to develop an acceptable methodology for incorporating fuel burnup credit in the subcriticality design of storage casks for spent reactor fuel. Specifically, this first task considers the subcriticality design of storage casks for fresh unburned fuel, develops a methodology for calculating the uncertainties and biases for computed *k*-effective values in criticality analyses, and establishes a uniform basis for evaluating subcriticality designs without burnup credit. The same principles used in this methodology for fresh fuel storage are expanded with additional nuclear parameters in the second and third tasks of the project to develop a methodology for incorporating fuel burnup credit in the design of storage casks for spent fuel.

UCID-21834

A Feasibility Study for Spent Fuel Burnup Credit in Storage Casks for Independent Spent Fuel Storage Installations

W. R. Lloyd

The work described here is the second of three planned tasks in a project to develop an acceptable methodology for incorporating fuel burnup credit in the subcriticality design of storage casks for spent reactor fuel. Task 1 of this project (already completed) developed a methodology for calculating the uncertainties and biases for computed *k*-effective values in criticality analyses. The Task 1 methodology covers fresh unburned fuel and establishes a uniform basis for evaluating subcriticality designs without burnup credit. In Task 2 (the subject of the present report) a feasibility study was performed for considering burnup credit for spent PWR fuels in a storage cask. The methodology of this study included modeling the depletion of ^{235}U, and the production of fissile plutonium and neutron-poison fission products with fuel burnup. Unlike previous studies, the methodology of our study also included modeling burnup variations along the length of the fuel rod, since burnup is typically lower at the ends of the rod than in the central portion. Results of the study show that certain subcriticality designs are feasible only when burnup credit is used, and also that burnup variations along the rod length must be included in any methodology for assessing subcriticality designs that use burnup credit. The variable burnup profile used in our study was taken from experimental reactor data, but it does not necessarily represent the bounding or worst-case profile that would result in maximum reactivity. It remains for Task 3 of this project to establish the bounding case and thus complete the goal of the project.

UCID-21863

Cost Estimate of High-Level Radioactive Waste Containers for the Yucca Mountain Project

E. W. Russell, H. A. Domian,* and A. A. Madson†

The Yucca Mountain site in southern Nevada is currently being characterized to determine its suitability for construction of the first United States high-level nuclear waste repository. The Site Characterization Plan (SCP) conceptual design specifies a metal container as the waste package for the permanent storage of this high-level waste. Lawrence Livermore National Laboratory (LLNL) is responsible for the selection of the container material and for modeling the performance of the container up to 10,000 years following the repository closure. A substantial part of the total cost for the proposed Yucca Mountain repository is to fabricate and certify the disposal containers. This report contains a structured cost estimate for the production of these containers. This cost estimate provides a baseline for future changes in configuration, material costs, and labor rates. LLNL, under contract to the U.S. Department of Energy (DOE) Office of Civilian Radioactive Waste Management (OCRWM)—Yucca Mountain Project (YMP), obtained cost estimates from qualified vendors experienced in related activities. The Babcock and Wilcox (B&W) Company of Lynchburg, Virginia, was selected because of their proven expertise in fabrication of large, similar-type components for the nuclear industry, and because of their past, related development work on the fabrication and closure of YMP containers. The B&W/vendor cost estimates reflect the SCP-referenced methods for fabricating and closing the containers at the repository surface facility. B&W/vendors also provided quality assurance (QA) and quality control (QC) cost factors for the container production cycle.

In addition to the cost estimates developed by B&W and vendors, Kaiser Engineers independently developed a detailed estimate for the QA/QC process expected to be implemented for the total production cycle. This evaluation was initiated because some preliminary vendor estimates were assessed by B&W as being low, principally in time allocated to complete the QA/QC functions. The Kaiser Engineers QA/QC cost evaluation is a "stand alone" analysis, not factored into cost estimates obtained from B&W/vendors.

*Babcock and Wilcox Company.
†Kaiser Engineering.

UCRL-98548ABST

Prescriptive Task Analysis for Plant Design

P. S. Schaich* and W. W. Banks

Prepared for 1988 Fourth IEEE Conference on Human Factors and Power Plants, Monterey, California, June 5–9, 1988.

We are analyzing operator tasks for a plutonium recovery plant before the plant is built – even before the design is finalized. Our task analysis precedes final design, and is thus prescriptive, enabling us to influence hardware design and work station layouts by human factors. We have an opportunity to tailor a work station to the operator rather than forcing him to work around a station poorly engineered from a human factors standpoint. This is important because task analysis done "up front," before design is finalized, provides an opportunity to pinpoint operational features that tend to increase human error potential and eliminate them from the design. Prescriptive task analysis provides an integrated systems approach to overall plant design, diminishing the need for costly retrofitting after plant construction. Furthermore, our prescriptive task analysis is a basis for generating time and motion data, useful in predicting operator exposure to radiation and plant production. It also validates interlock systems for safeguards. Since our prescriptive task analysis places constraints on hardware choices, it contributes to writing hardware and software specifications; again leading to an integrated systems approach—benefiting hardware and software engineers.

Prescriptive task analysis, through an iterative process, helps a good final plant design evolve in two ways. First, it uncovers oversights and flaws in design proposals widely believed to be very good. Second, it proves effective as an inexpensive but thorough method of refuting design proposals having defects not obvious to all plant project people. Detailed descriptions of operator tasks show plant project people, with different responsibilities and vested interests, the effects of a design proposal on plant operations. Consensus about a defective design proposal is more readily achieved. Reception to alternative design proposals is more open. Plant design evolves through a selection process where robust alternatives survive task analytic scrutiny.

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UCRL-102683

Accident Analysis and Safety Review of DOE Category B Reactors

C. Y. Kimura

Prepared for IANS Topical Meeting on the SAFOR, Boise, Idaho, September 30–October 4, 1990.

DOE is employing the principle of comparability with the NRC requirements to guide its safety program. The safety record of research reactors licensed by the NRC has been established and accepted. Comparing DOE orders (applicable to DOE research reactors) to NRC regulations (applicable to research reactors) could identify strengths and weaknesses of the DOE orders. The comparison was made in 14 general topics of safety labeled Areas of Safety Concerns. This paper focuses on the areas of accident analysis and safety review and presents recommendations in these areas.

UCRL-ID-103497ABST

Plutonium Air Transport Certification (PATC) Program, Phase One Final Report, Project 2: Development of *Draft Criteria for Package Drop* and Aircraft-Crash Tests

C. W. Walter

Recent U.S. legislation imposes new requirements for certification of Plutonium Air Transport Certification (PAT) packages. Public Law 100-203 establishes the manner in which the Nuclear Regulatory Commission (NRC) may approve and certify the safety of packages intended for transport of plutonium through the airspace of the United States while enroute from one foreign country to another foreign country. One of the provisions of the law requires that a package-drop test from aircraft cruising altitude be performed. Another provision requires, as an option, that an aircraft-crash test be conducted.

In response to a tentative request from the Power Reactor and Nuclear Fuel Development Corporation (PNC) of Japan for certification of a PAT package of PNC design, NRC requested LLNL to develop draft criteria for the package-drop test and the aircraft-crash test and to review the feasibility of performing the tests.

Assumptions with respect to the PAT package design, cargo aircraft, and loading arrangement were made to focus the work and permit quantitative analyses. However, both the draft test criteria which resulted, and the conclusion that conducting the tests is feasible, are not strongly dependent on these assumptions.

The law requires that a "worst-case" aircraft accident be considered to the maximum extent practicable as the basis for the aircraft-crash test. NRC specified that the crash of PSA Flight 1771 on December 7, 1987, represented the worst-case accident. The pertinent parameters of the accident were established on the basis of geotechnical investigations of the crash site and flight data recorder analysis so that comparable test conditions could be specified. Additional sources of

information were used to support the conclusions that the aircraft impacted on moderately hard, severely weathered and fractured shale and sandstone at 282 m/s at a trajectory angle of 60° to the hillside surface of the crash. The British Aerospace 146-200 aircraft remained intact until impact, even though it exceeded its certificated flutter-free speed. As a result of the high-speed impact, remaining fuel on the aircraft was rapidly ejected, burned briefly in the air above the crash point, and contributed no significant damage.

Draft criteria were developed and published for both the package-drop and aircraft-crash tests. Criteria for the package-drop test are based on aerodynamic analysis of free-falling objects. The criteria provide for consideration of arbitrary drop test altitude as long as the impact velocity exceeds specified requirements. An impact point accuracy analysis was performed to show the size of impact area required to insure that the package would land within it. A conceptual method for dropping the package is described and used to demonstrate that:

- The test is feasible.
- Suitable test ranges are available in the U.S.
- There are various options for a drop platform.

UCRL-ID-103534

Thermal Calculations Pertaining to a Proposed Yucca Mountain Nuclear Waste Repository

G. L. Johnson and D. N. Montan

To support the Yucca Mountain Project waste package and repository design efforts, LLNL conducted heat-transfer modeling of the volcanic tuff in the repository. The analyses quantify:

- Thermal response of a finite size, uniformly loaded repository where each panel of emplacement drifts contains the same type of heat source.
- Response given a realistic waste stream inventory to show the effect of inter-panel variations.
- Intra-panel response for various realistic distributions of sources within the panel.

The calculations, using the PLUS family of computer codes, are based on a linear superposition (in time and space) of the analytic solution of individual, constant output point sources located in an infinite, isotropic, and homogeneous medium with constant thermal properties.

UCRL-JC-103679ABST

U.S. DOE-AECL Cooperative Program for Development of High-Level Radioactive Waste Container Fabrication, Closure, and Inspection Techniques

E. W. Russell

Prepared for Combined ANS/ASME Nuclear Energy Conference, Newport, Rhode Island, September 16–19, 1990.

The U. S. Department of Energy (DOE) and Atomic Energy of Canada Limited (AECL) plan to initiate a cooperative research program on development of manufacturing processes for high-level radioactive waste containers. This joint program will benefit both countries in the development of processes for the fabrication, final closure in a hot-cell, and certification of the containers. Program activity objectives can be summarized as follows:

- To support the selection of suitable container fabrication, final closure, and inspection techniques for the candidate materials and container designs that are under development or are being considered in the U.S. and Canadian repository programs.
- To investigate these techniques for alternate materials and/or container designs, to be determined in future optimization studies relating to long-term performance of the waste packages.

The program participants will carry out this work in a conditional phased approach, and the scope of work for subsequent years will evolve subject to developments in earlier years. The overall term of this cooperative program is planned to run approximately three years.

UCRL-ID-103684ABST

Draft Criteria for Controlled Tests for Air Transport Packages

L. E. Fischer, J. H. VanSant, and C. K. Chou

Section 5062 of Public Law 100-203 imposes requirements on plutonium air transport (PAT) packages to be used to ship plutonium from one foreign nation to another through U.S. airspace. The law requires the U.S. Nuclear Regulatory Commission (NRC) to certify to Congress the safety of a PAT package design. The law also requires (for certification of a PAT package design) performance of an aircraft-crash test or *controlled tests that develop stresses in the* containment vessel greater than would occur during the aircraft-crash test. This document presents the draft criteria for the controlled tests.

These criteria are based on the accident conditions in an actual worst-case aircraft accident selected from documented severe aircraft accidents occurring world-wide during the last 38 years. The worst-case accident for impact is considered to be the PSA Flight 1771 crash in December, 1987. The impact conditions in the PSA accident have been closely studied and are the basis for the controlled test criteria for impact load—designed to test packages using the severe conditions required by law. Fire, puncture, and other accident parameters are also considered and are determined to be adequately addressed by the test criteria developed to satisfy Public Law 94-79.

UCID-LR-103735ABST

Investigation of the Crash Environment and Impact Conditions of the PSA Flight 1771 Aircraft Crash on December 7, 1987

C. E. Walter

A study of the PSA Flight 1771 crash on December 7, 1987, has been conducted to ascertain the general crash environment and impact conditions. This information was needed to determine the criteria for a possible aircraft-crash test that would produce conditions at least as severe as those produced in the PSA Flight 1771 crash, which has been specified by the Nuclear Regulatory Commission as representing the worst-case aircraft accident. Information from various sources was developed and analyzed, and additional studies and supporting exploratory tests were conducted. These activities were necessary because a detailed investigative report of the crash had not been prepared by the National Transportation Safety Board. The crash was not technically an "accident" but the result of a criminal act. The study includes determination of the geotechnical properties of the crash site, a topological survey, analyses of enroute radar data, estimates of the aircraft's final trajectory, examination of the distribution of aircraft debris from photographs of the crash site, laboratory impact tests of a scale model of the aircraft fuselage, review of witness observations on the *fire that followed the crash, analysis of the effect* of moist dust in a stoichiometric fuel-air mixture, flight simulations of the BAe 146-200 aircraft involved in the crash, review of aircraft integrity while operating outside its structural design envelope, reduction and analysis of terminal flight data from the badly damaged flight data recorder, analysis of the cockpit voice recorder tape, and searching (successfully) for a recorded seismic signal from the crash impact. The study concludes that the aircraft impacted at 00:14:35 UTC on December 8, 1987, at a speed of 282 m/s at a trajectory angle to the hill surface of 60°. The maximum Mach number did not exceed 0.86 in the time before the crash and was 0.83 at impact The ground at the impact point consisted of intensely weathered and fractured shale and sandstone. The aircraft was intact until impact. An airborne fuel-air fire of short duration occurred on impact, but contributed only negligibly to the crash damage. Conditions of the crash make it unlikely that a significant fuel-air explosion occurred.

UCRL-ID-103792

Human Factors Evaluation and Validation Criteria for Quality Training Programs: Development, Presentation, and Assessment

W. W. Banks

This paper provides LLNL managers with a rigorous and quantitative human factors method for assessing the development and validity of any training program at the Lab. A secondary purpose is to provide a checklist for course developers and evaluators. The checklist is easy to use and comprehensive, and it helps ensure that critical components of a training program are adequately addressed.

At the Lawrence Livermore National Laboratory, training programs are normally thought of as the province of individuals with a background in human resources, education, or a particular technical field. It is therefore unlikely that a Lab training program would be subjected to rigorous quantitative assessment involving:

- Statistical measurement and tests.
- Inferential calculations derived from applied principles of human behavior (applied psychology and learning theory).

This report attempts to demonstrate that the development and assessment of training programs could benefit from human factors engineering principle—criteria and quantitative assessment methods derived from the disciplines of applied psychology and quality assurance.

UCRL-ID-103851ABST

Design and Analysis of the Closure Bolts of Shipping Casks

T. Y. Lo and M. W. Schwartz

This report describes the design and analysis by hand calculations of closure bolts in shipping casks of radioactive materials. Loading conditions under 10 CFR 71 are discussed and the associated simplified analysis methods of bolt loads for these loading conditions are developed. A conservative method for determining the required preload to satisfy the leakage requirements of 10 CFR 71 is proposed. Stress limits and fracture toughness requirements for the closure bolts of shipping casks are recommended. A design procedure and a sample closure bolt design for a typical shipping cask are also included.

UCRL-MI-104096

MODIX Active Detector

R. E. Stewart,* M. R. Carter,* D. Whelan, H. C. Bruns, and C. J. Roberts

Drawings AAA88-104683-OA.

*L Division, Nuclear Test Experimental Science Program, LLNL.

UCRL-MI-104097

VJACS Detector Assembly (HyJacs Active Detector)

R. E. Stewart,* M. R. Carter,* D. Whelan, H. C. Bruns, C. J. Roberts, and T. J. Hancock

Drawings AAA87-107748-OA.

*L Division, Nuclear Test Experimental Science Program, LLNL.

UCRL-JC-104171ABST

Uncertainties in the Effects of Burnup and Their Impact on Criticality Safety Licensing Criteria

R. W. Carlson and L. E. Fischer

Prepared for Institute of Nuclear Materials Management 31st Annual Meeting, Los Angeles, California, July 15, 1990.

Current criteria for criticality safety for spent fuel shipping and storage casks are conservative because no credit is permitted for the effects of burnup of the fuel inside the cask. Cask designs that will transport and store large numbers of fuel assemblies (20 or more) must devote a substantial part of their payload to criticality control measures if they are to meet this criteria. The Department of Energy is developing data necessary to support safety analyses that incorporate the effects of burnup for the next generation of spent

fuel shipping casks. The efforts described here are devoted to the development of acceptance criteria that will be the basis for accepting safety analyses.

The consideration of criticality safety criteria including effects of burnup must be based on two principles:

- Criticality safety is assured even after two inadvertent operational or accidental errors.
- All uncertainties and biases are included in the evaluation of the criticality safety margin.

Preliminary estimates of the uncertainties of the effects of burnup have been developed to provide a basis for consideration of criticality safety criteria. The criticality safety margins in a spent fuel shipping or storage cask are dominated by the portions of a fuel assembly that are in low-power regions of a reactor core, and the reactor operating conditions are very different from spent fuel storage or transport cask conditions. Consequently, the experience that has been gathered during years of reactor operation does not apply directly to the prediction of criticality safety margins for spent fuel shipping or storage casks. The preliminary estimates of the uncertainties presented in this paper must be refined by both analytical and empirical studies that address both magnitude and interdependence of the uncertainties.

UCRL-JC-104186ABST

A Continuum Model for Lattice Structures with Geometric and Material Nonlinearities

D. B. McCallen and K. M. Romstad*

Prepared for *Computers and Structures*, Pergamon Press International Journal.

An equivalent continuum methodology offers an attractive alternative, or supplement, to classical discrete finite element procedures for the analysis of lattice structures. Effective continuum models can lead to reduced order models of lattice structures which are computationally very efficient. A number of continuum models have recently been proposed for analysis of lattice structures including one developed by the authors. The majority of these models have been concerned with linear analysis, although some work has been done in the area of geometrical nonlinearities. To the authors' knowledge, none of the existing continuum models have been extended to the analysis of lattices with general (i.e., both geometric and material) nonlinearities. The objective of the reported work was the development of a continuum model for general nonlinear analysis of lattice structures.

The formulation of a continuum procedure for general nonlinear behavior is given. A continuum finite element is derived and a computational algorithm for nonlinear analysis is outlined. A number of applications of the continuum method for classical elasto-plastic material constitutive behavior are presented and compared to discrete finite element solutions. The examples illustrate the potential economy of the continuum finite element analysis versus classical discrete finite element analysis.

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UCRL-JC-104193

Definition of Seismic Hazard for Use in Seismic Risk Assessment

D. L. Bernreuter, J. B. Savy, and R. W. Mensing*

Prepared for Probabilistic Safety Assessment and Management (PSAM), Beverly Hills, California, February 4–7, 1991
(Sponsor: Society for Risk Analysis).

Key to analysis of the risk to facilities posed by earthquakes is an appropriate description of the seismic hazard at the site in question. The seismic hazard is characterized for design purposes by a suitable earthquake level usually stated in terms of peak free-field ground acceleration. The higher the level selected, with respect to local seismic activity, the more conservative and expensive the design. Using

such point estimates of the hazard for a risk assessment is unsatisfactory. In recent times, full descriptions of the hazard over all earthquake levels, including uncertainties, have been developed. These seismic hazard descriptions are not only necessary for risk assessments, but aid designers and reviewers in assessing margins of safety.

To complete a seismic risk assessment, a full description of the earthquake response by the facility under review is also needed. These two descriptors (hazard and response curves) can be convolved to further the risk analysis. If the response is cast in terms of failure probability as a function of ground acceleration, then this convolution gives an estimate of the failure probability of the facility due to seismic events. Multiplying the failure probability by its consequence gives the risk.

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UCRL-JC-104204

CVMAC 2-D Program: A Method of Converting 3-D to 2-D

J. G. Lown

Prepared for 12th Annual International Computervision User Conference, Nashville, Tennessee, September 30–October 3, 1990.

This paper presents the user with a method of converting a three-dimensional wire frame model into a technical illustration, detail, or assembly drawing. By using the two-dimensional program, entities can be mapped from three-dimensional model space into two-dimensional model space, as if they are being traced. Selected entities to be mapped can include circles, arcs, lines, and points. This program prompts the user to digitize the view to be mapped, specify the layers in which the new two-dimensional entities will reside, and select the entities, either by digitizing or windowing. The new two-dimensional entities are displayed in a small view which the program creates in the lower left corner of the drawing.

UCRL-JC-104211ABST

Method of Calculating Test Leakage Rate for a Spent Fuel Cask

L. E. Fischer

This report presents a method for calculating containment test leakage rates of radionuclides from an example spent fuel cask. Three releasable radioactive sources are considered:

- Residual contamination in the cask cavity.
- Crud on the fuel elements.
- Radionuclides within the fuel rods.

The ANSI N14.5 standard is used to calculate the test leakage rates from the maximum permissible releases determined from 10 CFR 71 containment requirements.

UCRL-ID-104341ABST

Using the X-Ray Region of the Electromagnetic Spectrum for Alignment

R. B. Addis

Traditional alignment systems based on the use of visible light are not practical when opaque materials obstruct the alignment axis. X-ray alignment systems (XRA) have been designed specifically to overcome this limitation. XRA systems are analogous to visible light alignment methods; they both consist of placing an object to be aligned between a source of radiation and a detector. This report summarizes the interaction of the components which comprise an XRA system. Using physical principles and the knowledge developed by the traditional x-ray fields, general design guidelines are established. The specialized requirements for these systems are also provided, with analytical relationships for the basic alignment configurations being derived. These equations are used to predict the alignment error of a proposed system in addition to interpreting resulting alignment images. While this report establishes the limitations of this technique, it also reveals XRA has

some substantial advantages over optical methods. Besides ability to penetrate materials opaque to visible light, it is possible to eliminate all optical aberrations when using a polychromatic x-ray source. This results in true geometric optics, making measurements highly repeatable and accurate. This technique can readily position a fiducial within 0.001 in. of the alignment axis using off-the-shelf components. Typical alignment geometries are defined with an accuracy of 1 μrad through a distance of 100 ft. The ability of these systems to monitor the alignment in near real-time when using an x-ray camera is another advantage. This allows active alignment to be performed from a remote location prior to an experiment or through its duration.

UCRL-ID-104484ABST

Development of Criteria for Controlled Tests for Air Transport Packages

J. H. VanSant, L. E. Fischer, R. W. Mensing, J. C. Chen, T. F. Chen, C. K. Chou, J. Hovingh, and M. C. Witte

Packages intended for transport of plutonium through United States airspace while enroute from one foreign country to another must be certified by the Nuclear Regulatory Commission (NRC) as required by law. Section 5062 of Public Law 100-203 specifies an aircraft-crash test that replicates actual "worst-case" air transportation accident conditions. A provision of the law allows, in lieu of a crash test, "other tests," if accepted by the NRC. These tests must produce stresses in a plutonium air transport (PAT) container that are more severe than would be produced by a crash test.

The NRC requested LLNL to develop draft criteria for the "other tests" (designated controlled tests) and to conduct a preliminary evaluation of the feasibility of performing the tests. Developed criteria are based on worst-case accident conditions derived from reported aircraft accidents occurring from 1952 through 1989. The technical feasibility of the proposed criteria was evaluated by considering example methodologies for performing the tests.

The aircraft accident that developed the worst-case impact conditions for PAT cargo packages is the crash of PSA Flight 1771 on December 7, 1987. The British Aerospace 146-200 aircraft impacted at 282 m/s (925 ft/s) onto a hillside of severely weathered and fractured shale and sandstone. The proposed criterion for the controlled test is to impact a PAT test package at a velocity not less than 282 m/s onto a surface that has an effective hardness not less than the PSA Flight 1771 crash site hardness. An alternate controlled test is to impact a test package at a lower velocity onto an effectively unyielding surface. The lower impact velocity must be high enough to result in at least equivalent damage to the plutonium container.

We considered fire, puncture, and other accident parameters for specifying controlled tests. We determined that these parameters are adequately addressed by the established test criteria for compliance with Public Law 94-79, which all PAT packages must satisfy for certification by the NRC. These criteria include sequential tests that are: impact at 422 ft/s (129 m/s) onto an unyielding surface; crush; puncture; tear; and a 1-hr engulfing jet-fuel fire. From our review of aircraft accident reports, we find that longer large fires do not generally occur when the crash velocity is greater than 422 ft/s. In addition, we find that aircraft accidents involving impact at these velocities do not present conditions for crush and puncture that are more severe to PAT cargo packages than those developed by tests specified in NUREG-0360.

A statistical study of the reviewed accident data yielded 548 identified severe accidents (i.e., resulting in substantial damage or total loss) of large commercial jet aircraft. Over 91% of these accidents occurred during aircraft taxi, takeoff, climb, landing, and landing approach phases of flight.

UCRL-ID-104485ABST

Ballistic Analysis of Free-Falling PAT Packages

J. H. VanSant

This report contains the results of a study of ballistic characteristics of free-falling plutonium air transport (PAT) packages. The study provides information to support the criteria for a PAT package drop test and a target accuracy analysis. Should the postulated drop test be performed, a package will be released from an aircraft and allowed to fall freely to the ground. The principal influences on package ballistics are the ballistic number, air density, and wind velocity. The ballistic values were calculated using a finite difference computing method. The results obtained by this method are in good agreement with the values obtained from closed-form equations. Characteristic curves are presented for the example package (2.4- × 1.2-m-diam cylinder weighing 2.6 mg). A general correlation for the sea-level-impact velocity of objects with respect to a characteristic parameter (defined as the ballistic number and the package ballistics) for a suggested drop method is presented. The method suggested makes use of drag parachutes to provide a low horizontal package velocity as the package is released from the drop aircraft. Only a portion of the data generated for this study is presented to show examples of package ballistics. Packages to be drop-tested may have characteristics that are different from those presented in this report.

UCRL-ID-104553ABST

Technical Feasibility of a PAT Package Drop Test

C. E. Walter

This report reviews the technical feasibility of drop-testing a plutonium air transport (PAT) package to satisfy a requirement of Public Law 100-203. All principal tasks that must be done to complete the test program are identified and methods for accomplishing the tasks are suggested. At least one of several candidate test ranges is an acceptable test site, a C-130 aircraft is the example drop-test aircraft, and tracking radar and cinetheodolite cameras are the example equipment for tracking the test package during free fall and measuring its trajectory parameters. The results of this review indicate that the test criteria for a PAT package drop test are technically feasible and the test can be successfully accomplished.

UCRL-ID-104554ABST

Mechanical Properties of Rocks from PSA Flight 1771 Crash Site

C. E. Walter

Geotechnical properties of the near-surface rocks at the PSA Flight 1771 crash site have been determined from a variety of laboratory tests and measurements on cylindrical rock samples prepared from specimens derived from subsurface drill cores and from surface outcrop and "float" material. Pressure-volume tests to determine bulk modulus were conducted on specimens 2.54-cm (1-in.) and 5.08-cm (2-in.) diam at pressures up to 480 MPa. The uniaxial compressive strengths for both groups of samples were also measured. Results show that the uniaxial strength is proportional to the density of the intact rock samples. The uniaxial strength is also dependent on the sample orientation with respect to bedding planes. Triaxial compression tests were conducted on both groups of samples at pressures between 25 and 500 MPa to investigate the effect of confining pressure on stress-strain behavior. As confining pressure was elevated, the strength increased and material response changed from brittle fracture to ductile, strain-hardening behavior. Strain rate effect was investigated at confining pressure of 25 and 50 MPa for strain rates between 10^{-4} and 20/s. Ultimate strength and Young's modulus were observed to increase with increasing strain rate. Dry densities and porosities for selected samples were also measured.

UCRL-ID-104556ABST

Constitutive Models and Dynamic Behavior of Soils Under Impact

C. E. Walter

On December 7, 1987, PSA Flight 1771 crashed to the ground on a hillside southwest of Paso Robles, California. The crash impact created a crater-like indentation in the ground, displacing a large quantity of soil and rock in the process. Although a disastrous event, this plane crash nevertheless affords an opportunity to utilize a well-documented case history to evaluate the behavior of geologic materials under such impact loading and to verify and calibrate methods used to analyze and test the integrity of proposed air transport container designs for shipment of plutonium nuclear fuel. This study, which is part of the overall analysis and verification effort for plutonium air transport package designs, characterizes the "harder" (i.e., stiffer and stronger) response of soils to high rates of loading and high levels of stress such as imposed by the impact of an airplane or other projectile. Data available in the published technical literature, as well as some unpublished data, have been examined and interpreted to provide a basis for quantifying the response to high strain rates and stress levels of soils at the PSA crash site and other sites that may be used for testing the integrity under high-speed ground impact of proposed plutonium air transport package designs. Geotechnical characterization of the PSA crash site soils has been performed based on extensive field exploration, field penetration testing, and laboratory testing. The soils at the crash site consist of alluvium and residual soils formed by in-place weathering of rock. The engineering properties and behavior of these soils are consistent with those of other similar soils. The characterized engineering properties have been used to develop site-specific parameters for implementation of analytical modeling of airplane crash impacts using the computer program DYNA3D.

UCRL-ID-104557ABST

PATC-IR 89-03, Fuselage Model Crash Tests

B. C. Davis, C. E. Walter, and C. K. Chou

A series of model "crash" tests have been conducted for the purpose of understanding the mechanisms which produced the catastrophic shattering and fragmentation associated with the crash of PSA Flight 1771. Public Law 100-203 defines conditions under which air transportation of plutonium from a foreign nation to a foreign nation through United States airspace may be permitted. Section 5062 of that law specifies that proof of survivability of the packaging, with no leakage of plutonium, shall be provided for a "worst-case" accident, and that the proof of survivability shall be demonstrated by, among other requirements, an aircraft-crash test which replicates the worst-case accident. The U.S. Nuclear Regulatory Commission (NRC) has specified that the conditions associated with the crash of PSA Flight 1771 represent the "worst case." The accident occurred near Paso Robles on December 7, 1987. Shattering and fragmentation of every physical aspect of the aircraft, including its contents, characterized the crash conditions. A short-term, yet intense effort has been applied toward understanding the phenomena which produced global shattering/fragmentation. Ten tests were conducted, using a 2.5-in.-diam gas gun, in an effort to reproduce the PSA Flight 1771 shattering conditions in model fuselages. Five phenomenological shatter-producing candidates emerged. They were:

- High-strain rate.
- High-deformation rate.
- Air pressure buildup inside the fuselage on impact.
- "Shrapnel" from fragmenting rigid/semi-rigid mass internal to the fuselage.
- Eruption of deformable mass internal to the fuselage.

The tests demonstrated that superposition of either of the latter three "shatter-producing" candidates on the first two (high-strain rate and high-deformation rate), would produce catastrophic shattering.

UCRL-ID-104560

PATC-IR 89-04, An Engineering Geologic Evaluation of the PSA Flight 1771 Crash Site Near Paso Robles, California

D. W. Carpenter,* J. C. Chen, and G. S. Holman

At 15:30 PST on December 7, 1987, Pacific Southwest Airlines (PSA) Flight 1771, with 43 passengers and crew, departed from Los Angeles, California bound for San Francisco, California. At approximately 16:15 PST, probably as the result of a criminal act, the British Aerospace 146-200 employed for PSA Flight 1771 crashed with great force into a hillside about 19 km (12 miles) southwest of Paso Robles, California. The aircraft broke into small pieces on impact and its contents were widely scattered. There were no survivors.

The purpose of this report is to present the results of an engineering geologic study of the crash site and its environs. This study was undertaken by Lawrence Livermore National Laboratory (LLNL) at the request of the U.S. Nuclear Regulatory Commission (NRC) in order to assist the NRC in its response to Section 5062 of Public Law 100-203.

Section 5062 is concerned with air shipments of plutonium (Pu) from one foreign nation to another through U.S. airspace. It applies specifically to the packages or containers in which the Pu is shipped, requiring that they be certified by the NRC as safe for the purpose and that they must be able to survive the worst aircraft accident that might occur while in transit without releasing significant quantities of their Pu contents.

The law sets forth general requirements for certifying a shipping package as safe including a drop test of the package and a crash test of the cargo aircraft, or equivalent, with test packages aboard. The crash test can be waived if other tests used to develop the package can be shown to produce at least as severe an environment for the test packages.

The NRC has determined that, because of flight conditions believed to have been existing at impact, the PSA Flight 1771 crash represents a worst case crash as required by Section 5062. In order to assure adequacy of testing, the geotechnical characteristics of the aircraft crash site must be similar or more resistant to impact than the site where PSA Flight 1771 crashed. The investigation reported herein was undertaken to determine the engineering geology of the crash site and to obtain samples for rock and soil testing in order to further other geotechnical studies of the site. These investigations were necessary in order to geotechnically characterize the crash site so that the applicant for U.S. NRC safety certification of the package is able to determine whether its proposed test site(s) is adequate under the test criteria. A detailed description of the field investigation is provided as part of this report.

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UCRL-ID-104572ABST

Safety Implications of Burnup Effects in Criticality Safety Margins for Spent Pressurized Water Reactor Fuel Transport and Storage

R. W. Carlson and L. E. Fischer

Criticality safety margins must be based on the combination of the best available prediction of the margin and all uncertainties in the prediction. Inclusion of the effects of burnup in the evaluation of spent fuel shipping or storage casks must be based on a thorough understanding of the prediction of the effects of burnup and the uncertainties in the measurements (or predictions) of burnup and predictions of the effects.

This report presents a preliminary estimate of the effects of burnup and its uncertainties. This will serve as the first step in the effort to develop acceptance criteria that assure public safety. An assembly average burnup of 20,000 MWD/MTU represents an increase in the criticality safety margin of about 20% (δ k/k), and the current estimate of the uncertainty in this value is close to 4% (δ k/k). The uncertainties in the components of the effects of burnup were based on relevant literature citations and—where no other information was available—on estimates. Consequently, the margins and uncertainties in the margin presented here should be considered as initial estimates on which more refined analyses should build to develop a defensible basis for predicting and reviewing the criticality safety margins which include the effects of burnup.

UCRL-ID-104576ABST

Structural Impact Analyses

M. C. Witte

Section 5062 of Public Law 100-203 is concerned with air shipment of plutonium from one foreign country to another through United States airspace. It applies specifically to the packages in which the plutonium is shipped, requiring that the packages be certified by the NRC as safe for that purpose and be able to survive the worst-case aircraft accident without releasing significant quantities of plutonium.

The law requires actual tests to be conducted in the certification process. Actual tests include drop tests of the package or a crash test of the cargo aircraft with test packages aboard to replicate actual worst-case aircraft accident conditions unless the stresses produced by design tests exceed the stresses produced by actual crash tests. The NRC specified that the conditions associated with the crash of PSA Flight 1771 on December 7, 1987, represent a worst-case aircraft accident and therefore are suitable for use as the basis for conducting the required tests.

In order to assure adequacy of testing (both of individual packages and cargo aircraft) a series of analyses have been performed. This report documents the analyses performed for a basis package and for simplified models of two aircraft fuselages.

UCRL-JC-104577ABST

Atmospheric Ray-Propagation Code

S-W Kang and J. L. Levatin*

A numerical code called Livermore Atmospheric Propagation (LAP) has been developed to calculate blast-wave propagation characteristics in the atmosphere under weather conditions that vary in both vertical and downrange directions. Previous ray-trajectory analyses have treated the case of the uniform (throughout the region of interest) vertical sound velocity profile. When the downrange weather conditions are also taken into account, calculated results show ray propagation behavior is greatly affected by downrange conditions as well as vertical sound velocity profile effects.

*Scientific Software Division, Computation Directorate, LLNL.

UCRL-ID-104578ABST

PAT Package Drop Test—Target Accuracy Analysis

R. E. Glaser* and J. H. VanSant

In this report we present the results of a statistical analysis of the target accuracy of a plutonium air transport (PAT) package drop test. The test package must be released from an aircraft at a predetermined location and fall within a designated target area to ensure safety of people on the ground and successful photography of the package during its descent and impact. The probable target-miss distance is estimated by using an example package drop methodology and its associated parameter values and assumed errors. The example drop method provides for dropping a 2.6-Mg test package from a C-130 aircraft flying into the wind at an altitude of 7.6 km (25,000 ft). For the drop from the aircraft, the package is fastened to a pallet that is connected to a drag parachute. At a preset time after the drop, the package is automatically released from the pallet for free fall. We obtained probability distributions of the target-miss distance by Monte Carlo simulation. The results indicate that the probability a test package will impact within an 881-m radius from the target is 99%. The mean target-miss distance is estimated to be 413 m.

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UCRL-JC-104581SUM

Consequence Evaluation of Hypothetical Reactor Vessel Support Failure Due to Radiation Embrittlement

S. C. Lu, G. S. Holman, and H. E. Lambert*

Prepared for 11th International Conference on Structural Mechanics in Reactor Technology, Tokyo, Japan, August 18–23, 1991.

This paper describes a consequence evaluation to address safety concerns raised by the radiation embrittlement of the reactor pressure vessel (RPV) supports for a nuclear power plant. The study comprises a structural evaluation and an effect evaluation and assumes that all four reactor vessel supports have completely lost the load carrying capability.

By demonstrating that the ASME code requirements governing Level D service limits are satisfied, the structural evaluation concludes that the reactor coolant loop (RCL) piping is capable of transferring loads to the steam generator (SG) supports and the reactor coolant pump (RCP) supports. A subsequent analysis further demonstrates that the SG supports and the RCP supports have sufficient design margins to accommodate additional loads transferred to them through the RCL piping.

The effect evaluation employs a systems analysis approach as the RPV is subject to movements caused by the RPV support failure. Initiating events and the ability of the engineered safeguard systems to identify a number of areas of additional safety concerns are investigated:

1. The RPV movements could cause multiple rupture of instrumentation thimble tubes or the guide tubes that penetrate the bottom of the RPV and result in a loss of core coolant that may uncover the core.

2. The deformation of the RCP casing may cause the impellers to bind and result in loss of natural circulation. Tilting of the pump may affect its coastdown ability.
3. The control rods could bind with tilting of the RPV and ability to insert control rods during a reactor trip may be affected.
4. The rupture of the 10-in. safety injection lines could impair the function of the emergency core cooling system.

Further investigation concludes that a hypothetical failure of the RPV supports due to radiation embrittlement will not result in significant safety concerns.

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UCRL-ID-104582ABST

Development of Soil/Rock Constitutive Models and Benchmark Analysis for Gas-Gun Penetration Tests at the PSA Flight 1771 Crash Site

J. C. Chen and M. C. Witte

A series of studies has been conducted for the purpose of understanding the crash environment and impact conditions of the PSA Flight 1771 crash on December 7, 1987, which has been specified by the Nuclear Regulatory Commission as representing the "worst-case" accident. This information is needed for establishing the criteria for suitable package development tests and for an aircraft-crash test that would replicate the conditions of the PSA Flight 1771 crash.

The work reported here is part of the study defining the aircraft impact environment. In particular, the results of the geotechnical investigation of the PSA Flight 1771 site are summarized here. The site characteristics and the geotechnical properties at the PSA Flight 1771 crash site were developed from extensive field investigations and laboratory tests. Field investigations consisted of topography surveys, exploratory borings, seismic refraction measurements, and dynamic penetration tests. Laboratory tests measured the basic material properties, compressibility characteristics, and the stress-strain behaviors of the soil/rock samples. The results of laboratory tests were used for the development of soil/rock constitutive models for dynamic impact analysis.

Four gas-gun penetration tests were conducted at the PSA Flight 1771 crash site. The results and the data of the penetration tests were used as a benchmark of the developed constitutive model and finite element codes DYNA2D and DYNA3D. These codes were used for conducting impact-crash analyses in support of the criteria for development (controlled) tests used in the design of plutonium air transport packages. Input parameters for the best-estimate, the upper- and lower-bound models were developed and provided for the PSA Flight 1771 crash site. In addition, three other soil models are also provided for conducting finite element impact analyses that provide a methodology for establishing the equivalence between impact velocity of a package on an arbitrary surface and an unyielding surface.

UCRL-ID-104585ABST

Technical Feasibility of a PAT Aircraft-Crash test

C. E. Walter

This report reviews the technical feasibility of crashing an aircraft containing plutonium air transport (PAT) test packages to satisfy a requirement of Public Law 100-203. All principal tasks that must be done to complete the test program are identified and methods for accomplishing the tasks are suggested. At least one of several candidate test ranges is an acceptable test site. A Boeing 707 aircraft, equipped with a remote guidance system and having appropriate structural modifications, is the example test aircraft. The results of this review indicate that the test criteria for the aircraft-crash test are technically feasible and can be successfully accomplished. Preparation for the test will require development of a guidance system and completion of all structural modifications needed to successfully fly the aircraft during conditions preceding the crash. Access to existing data on the structural and flight characteristics of the test aircraft is necessary to complete these tasks.

UCRL-JC-104588ABST

Integrating Human Factors Expertise into the PRA Process

J. E. Wells and T. G. Ryan*

Prepared for Probabilistic Safety Assessment and Management (PSAM), Beverly Hills, California, February 4–7, 1991 (Sponsor: Society for Risk Analysis).

Human error is a primary contributor to risk in high-reliability systems. A 1985 U.S. Nuclear Regulatory Commission (USNRC) study of Licensee Event Reports (LERs) suggests that upwards of 65% of commercial nuclear system failures involve human error. Because of the importance of human actions within a commercial nuclear power plant, the USNRC initiated research directed toward integrating human factors and hardware engineering expertise throughout the probabilistic risk assessment (PRA) process. Success in this area is important to the credibility of future PRAs. This paper presents a method for integrating broad-based human factors expertise into the PRA process and describes the field evaluation.

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UCRL-CR-104834ABST

Seismic Margin Review of Plant Hatch Unit 1: Systems Analysis

D. D. Orvis and P. Moieni

This report documents the approach, results, and engineering insights for the systems analysis portion of the seismic margins analysis (SMA) of Plant Hatch, Unit 1. The systems analysis was performed by Accident Prevention Group (APG) under contract to Lawrence Livermore National Laboratory (LLNL). The purpose of the study was to employ the event/fault tree methods as recommended in NUREG-CR-4482 as an independent assessment of the seismic margins for Hatch. A parallel assessment was conducted by Southern Company Services (SCS) and their consultants using the "success path" approach developed by Electric Power Research Institute (EPRI NP-6041). The systems analyses portions of the respective studies are independent but the assessment of seismic capacities of components and structures are not.

The SMA assumes that a seismic margin earthquake (SME) of 0.3-g peak ground acceleration occurs for Plant Hatch and off-site power is lost to the plant for 72 hr. Experience in other studies has shown that many components possess margins to seismically induced transients even at the SME level. The margins to failure of components is expressed as high-confidence of low-probability of failure (HCLPF) in units of peak ground acceleration (PGA–g). Nevertheless, safety systems and their supporting electrical and cooling water systems are subject to various random- and common-cause failures and human actions as well as seismically induced transient. The systems analysis is structured to identify potential seismic and nonseismic failure modes and/or combinations of such failures that could prevent safe shutdown of the plant, and to quantify their relative probabilities.

UCRL-ID-104845ABST

Consequence Evaluation of Radiation Embrittlement of Trojan Reactor Pressure Vessel Supports

S. C. Lu, S. C. Sommer, G. L. Johnson, and H. E. Lambert

This report describes a consequence evaluation to address safety concerns raised by the radiation embrittlement of the reactor pressure vessel (RPV) supports for the Trojan nuclear power plant. The study includes a structural evaluation and an effect evaluation, and assumes that all four reactor vessel supports have completely lost the load carrying capability.

By demonstrating that the ASME code requirements governing Level D service limits are satisfied, the structural evaluation concludes that the Trojan reactor coolant loop (RCL) piping is capable of transferring loads to the steam generator (SG) supports and the reactor coolant pump

(RCP) supports. A subsequent analysis further demonstrates that the SG and RCP supports have sufficient design margins to accommodate additional loads transferred to them through the RCL piping.

The effects evaluation, employing a systems analysis approach, investigates initiating events and the reliability of the engineered safeguard systems as the RPV is subjected to movements caused by the RPV support failure. The evaluation identifies a number of areas of additional safety concerns:

1. The RPV movements could cause multiple ruptures of instrumentation thimble tubes or the guide tubes that penetrate the bottom of the RPV and result in a loss of core coolant that may uncover the core.
2. The deformation of the RCP casing may cause the impellers to bind and result in loss of natural circulation. Tilting of the pump may affect its coastdown ability.
3. The control rods could bind in the event of RPV tilting and the ability to insert control rods during a reactor trip may be affected.
4. The rupture of the 10-in. safety injection lines could impair the function of the emergency core cooling system.

Further investigation concludes that a hypothetical failure of the Trojan RPV supports due to radiation embrittlement will not result in significant safety concerns.

UCRL-JC-104854ABST

TOPAZ2D Benchmark Problems

A. B. Shapiro

The heat transfer code TOPAZ2D has been under development at the Lawrence Livermore National Laboratory since 1982. The need for software quality assurance (SQA) has always existed. The level of recognition for SQA and effort to accomplish it, however, has fluctuated over time. A variety of reasons including deadlines, staff, and embarrassment resulting from having to retract releases have all contributed to either less or more attention being paid to SQA. The result was a periodic rise and fall of complaints by the users, pointing out problem areas, and pleas for improvement.

This year we began an SQA program to validate the TOPAZ2D heat transfer code. Our objective is to develop an automatic test suite of benchmark problems. To date we have run and documented 30 problems. Two of the more interesting benchmark problems are presented in this paper.

Problem 1. An anomalous result from a TOPAZ simulation of the heating of a laser lens was reported. The lens had an initial condition of 25°C and was placed in a hot environment. Physically, the lens had to heat up. However, there were several nodes that cooled down. A simple problem with an analytical solution was formulated to investigate this anomalous behavior. Four heat transfer codes were used on the problem. Three codes gave anomalous results. And, although the calculated temperatures are physically wrong, the values are closer to the analytical answer than the more physically pleasing values calculated by the fourth code.

Problem 2. One-dimensional transient heat transfer in a slab with constant heat flux on the front face and adiabatic conditions on the other face. The thermal conductivity and heat capacity vary with temperature such that the thermal diffusivity remains constant. Results for Crank-Nicolson versus fully implicit time integration; material properties evaluated at the Gauss integration point temperature versus element average temperature; and fine zoning versus coarse zoning are presented. Unnatural anomalies are observed in the early-time temperature response at nodal locations near the front face. The late-time temperature response converges to the analytical answer for all cases.

UCRL-ID-104856

AUTOCASK—*AUTO*matic Generation of 3-D *CASK* Models

M. A. Gerhard and S. C. Sommer

From the inception of commercial nuclear power production to this day, spent fuel has been accumulating in reactor fuel pools across the country. When a permanent nuclear waste repository is established as required by Federal law, this fuel will be shipped from the reactor sites to the repository. In anticipation of increased license submittals for spent fuel shipping casks, the U.S. Nuclear Regulatory Commission requested the Lawrence Livermore National Laboratory (LLNL) to develop an integrated software system to conduct confirmatory analyses of the casks. The purpose of the analyses is to ensure structural integrity under a series of normal operating loads and hypothetical accident loads as specified in Title 10 of the *Code of Federal Regulations* (1983).

AUTOCASK is a microcomputer based system of computer programs developed by LLNL for the structural analysis of shipping casks for radioactive material. *AUTOCASK* is composed of a series of menus, input programs, display programs, terminal programs, and archive programs. An analysis is performed by preparing the necessary input data and then creating a model file which is transferred over the telephone line to the Open Computing Facility (OCF) at LLNL. On the OCF, a mesh generator program converts the model file into a three-dimensional finite element analysis input file. An additional program completes the finite element input by adding analysis parameters, material properties, and loading conditions. Finally, a quasi-static analysis is performed using an LLNL-developed finite element program, and the results are displayed graphically on the PC terminal. Graphic output can also be printed.

UCRL-ID-104864

The Mechanical Response to Impact of a Representative PAT Package

T. F. Chen

The Plutonium Air Transport Certification (PATC) project currently being conducted by the Nuclear Systems Safety Program (NSSP) for the U.S. Nuclear Regulatory Commission consists of two projects. Project 1 is the development of draft controlled test criteria; Project 2 is the development of draft drop and aircraft-crash test criteria. Project 1 requires, in part, that the controlled impact environment be defined and, ideally, a set of distinct controlled tests that simulate the "worst-case" aircraft accident be specified independent of package design or accident impact surface. However, due to the extraordinarily high impact velocity of 925 ft/s involved in the worst-case aircraft accident, it is extremely difficult to accurately specify a package-independent equivalent impact velocity onto an unyielding (easily defined) surface. In pursuit of this objective, a representative PAT package had to be selected and analyzed for its mechanical impact response in this severe impact environment to establish a family of equivalent impact velocity curves to aid in development of controlled impact test criteria.

After successfully benchmarking the finite element impact analysis of this representative package against impact test measurements of a similar package, we used the demonstrated finite element model to generate the corresponding equivalent impact velocity curves. For impact velocities beyond the package survivable limits, we adapted an "energy balance" approach in the derivation of equivalent package impact velocity curves. The range in impact velocity ratios found for this representative package is within the bounds of previously designed transportation packages.

Even though the equivalent impact velocity curves presented in this report are package-dependent, the methodology we describe should be readily applicable to packages of different sizes or configurations.

UCRL-JC-105146

Human Factors Assessment in PRA Using Task Analysis Linked Evaluation Technique (TALENT)

J. E. Wells and W. W. Banks

Prepared for 18th Water Reactor Safety Info. Meeting, Rockville, Maryland, October 23–24, 1990.

Human error is a primary contributor to high-reliability systems unreliability and risk. A 1985 U.S. Nuclear Regulatory Commission (USNRC) study of Licensee Event Reports (LERs) suggests that more than 65% of commercial nuclear system failures involve human error. Because of the importance of human actions within a commercial nuclear power plant, the USNRC initiated research directed toward integrating human factors and hardware engineering expertise throughout the probabilistic risk assessment (PRA) process. Success in this area is important to the credibility of future PRAs. This paper presents a method for integrating broad-based human factors expertise into the PRA process.

This method is known as TALENT (Task Analysis Linked Evaluation Technique). TALENT focuses on joining source data, quantification methods, and broad-based human factors expertise. TALENT uses products from other areas of the USNRC reliability assessment research program, other reliability assessment research programs within the U.S., international commercial nuclear communities, and nonnuclear research programs. TALENT implementation procedures take full advantage of earlier guidelines published by the NRC for conducting PRA studies, such as PRA Procedures Guide, IREP Guide, and NREP Guide; and guidelines developed inside and outside the NRC to integrate human reliability analysis (HRA) and PRA, such as a TEEM and SHARP, respectively.

This process is expected to achieve results that:

1. Provide more realistic estimates of the impact of human performance on nuclear power safety.
2. Can be fully audited.
3. Provide a firm technical base for equipment- and personnel-centered retrofit/ redesign of plants, enabling them to meet internally and externally imposed safety standards.
4. Yield human and hardware data capable of supporting inquiries into human performance issues that transcend the individual plant.

UCRL-ID-105148

Seismic Hazard Characterization of the BNL-HFBR Site (Upton, New York)

J. B. Savy

In an effort to develop estimates of the seismic hazard at HFBR, the Lawrence Livermore National Laboratory, through DOE/BNL, was asked to use its latest methodology and data banks.

The scope of this study is to perform for the HFBR site the same kind of calculation as performed for the Nuclear Regulatory Commission (NRC), using the same methods and data as those used for all the active nuclear power plant (NPP) sites located east of the Rocky Mountains.

The study for NRC was specifically designed to provide a set of tools to estimate the hazard at all the plant sites in the Eastern United States (EUS). However, it must be noted that the specific characteristics of each plant site are accounted for in a generic fashion. For example, the local site corrections used eight different site categories rather than any site-specific factors. In addition, the models of seismicity developed did not concentrate on any specific site locations, but were provided for the entire EUS. Similarly, the ground motion models used in the analysis did not concentrate on small regions. They were separated in four different groups of models applicable to the four areas in the EUS: North East, South East, North Central, and South Central. The results provided by the NRC/LLNL methods with the present data banks are accurate enough to be used in screening techniques and for preliminary analyses. If a detailed site-specific analysis were deemed necessary, a careful revisiting and possible update of each of the links in the chain of analyses leading to the final data base would be appropriate.

The parameters of interest in the present study are:

- The peak ground acceleration considered to be at the site location in the free field.
- The pseudo velocity response spectrum of the free field motion for 5% critical damping and at five frequencies.

UCRL-JC-105437ABST

Computational Model for Optimizing Longitudinal Fin Heat Transfer in Laminar Internal Flows

C. S. Landram

Prepared for ASME National Heat Transfer Conference, Minneapolis, Minnesota, July 26–31, 1991.

Optimal configurations are identified (based on a numerical model) for fully developed laminar internal flows whose base boundary walls have perpendicular fins extending longitudinally into the fluid. The optimum coolant flow channel (formed between each fin) has an aspect ratio dependent on the coolant-to-wall thermal conductivity ratio and on the fin-to-channel width ratio, which is optimally about unity. A base thickness exists which minimizes the base hot-spot temperature. Its value depends on the fin-to-channel width ratio.

UCRL-JC-105441ABST

Deterministic Seismic Design and Evaluation Criteria to Meet Probabilistic Performance Goals

S. A. Short,* R. C. Murray, T. A. Nelson, and J. R. Hill†

Prepared for 3rd Symposium on Current Issues Related to Nuclear Power Plant Structures, *Equipment, and Piping, Orlando, Florida,* December 5–7, 1990.

For U.S. Department of Energy (DOE) facilities across the United States, seismic design and evaluation criteria are based on probabilistic performance goals. In addition, other programs such as Advanced Light Water Reactors, New Production Reactors, and IPEEE (for commercial nuclear power plants) utilize design and evaluation criteria based on probabilistic performance goals. The use of probabilistic performance goals is a departure from design practice for commercial nuclear power plants which have traditionally been designed utilizing a deterministic specification of earthquake loading combined with deterministic response evaluation methods and permissible behavior limits. Approaches which utilize probabilistic seismic hazard curves for specification of earthquake loading and deterministic response evaluation methods and permissible behavior limits are discussed in this paper. Through the use of such design/evaluation approaches, it may be demonstrated that there is high likelihood that probabilistic performance goals can be achieved.

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UCRL-JC-105670ABST

Criteria and Feasibility Review for a Severe Cargo Aircraft-Crash Test

C. E. Walter

Prepared for 1991 American Society of Mechanical Engineers (ASME) Pressure Vessel and Piping Division Meeting, San Diego, California, June 23–27, 1991.

Recent U.S. legislation establishes the manner in which the U.S. Nuclear Regulatory Commission (NRC) may approve and certify the safety of packages intended for plutonium transport through U.S. airspace enroute from one foreign country to another. One of the provisions of this law requires that a package-drop test from aircraft cruising altitude be performed. (A companion paper in this session addresses the drop test considerations.) In addition, another provision requires, as an option, that a crash test of the actual cargo aircraft be conducted. NRC asked us to develop draft criteria for the aircraft-crash test and to review the feasibility of performing the test. We made assumptions with respect to the package design, cargo aircraft, and loading arrangement to focus the work and permit quantitative analyses. However, both the draft test criteria which resulted and the conclusions that the test is feasible are not strongly dependent on these assumptions.

The law requires that a "worst-case" aircraft accident be the basis for the aircraft-crash test. NRC specified that the crash of PSA Flight 1771 on December 7, 1987, represented the worst-case accident. We established the pertinent parameters of the accident on the basis of geotechnical investigations of the crash site and flight-data recorder analysis so that comparable test conditions could be specified. We used additional sources of information to support the conclusions that the aircraft impacted on a moderately hard, severely weathered and fractured shale and sandstone hillside surface at 282 m/s at a trajectory angle of 60° to the local terrain. The British Aerospace 146-200 aircraft remained intact until impact even though it exceeded its certificated flutter-free speed. As a result of the high-speed

impact, remaining fuel on the aircraft was rapidly ejected, burned briefly in the air above the crash point, and contributed no significant damage. Specified draft criteria for the aircraft-crash test are consistent with the conditions encountered in this basis accident. The criteria include provisions for consideration of alternative test aircraft because it was found that aircraft alternatives are available that could considerably lower the cost of the test without compromising test results. It appears that a suitable test range is available, a test aircraft can be modified to fly as required, and the aircraft-crash test is feasible.

UCRL-JC-105761ABST

Thulium Heat Sources for High-Endurance and Energy-Density Power Systems

C. E. Walter, J. H. VanSant, J. E. Kammeraad,* and R. VanKonyenburg†

Prepared for the 26th Intersociety Energy Conversion Engineering Conference, Boston, Massachusetts, August 3–9, 1991.

Availability of high-endurance and energy-density (HEED) power systems would enhance current applications such as new missions for autonomous underwater vehicles (AUV). We are studying the performance characteristics of radioisotope heat source designs for HEED power systems that utilize thulium-170 in the power range of 5 to 50 kW_{th}. Heat sources in this power range, coupled with overall power conversion efficiencies of ~30%, would easily satisfy the current AUV missions. New Navy missions, not previously possible, can now be considered because thulium isotope power (TIP) systems have two-to-three orders-of-magnitude higher endurance and energy density than found in the chemical- and electrochemical-based power systems being considered. Thulium-170 has several attractive features, including the fact that it decays to stable ytterbium-170 with a half-life of 129 d (four months). This characteristic seems reasonable for terrestrial applications since refueling on that time scale should be acceptable in view of the advantage of its benign decay.

The characteristics of three heat source designs in the 5- to 50-kW_{th} power range are given. The designs consider the manner of isotope production, shielding requirements, integration with power conversion components, safety, and environmental aspects. Tm-170 has present as the oxide (Tm_2O_3) intermixed with a low-Z material (carbon or beryllia). The resulting material is quite refractory, allowing power conversion at high peak temperature. Alternative methods for transferring heat to the conversion system have been considered. Reserve heat pipes can be included to assure passive cooling of this "always on" heat source. Beta radiation from Tm-170 stopped in a low-Z material minimizes production of bremsstrahlung radiation and consequently shield thickness. The material in this form is also compatible with irradiation of Tm-169 in a high-energy-spectrum, high-flux reactor. The cross section of Tm-169 is so high that a diluted material is required to prevent excessive flux depression during irradiation. Calculations indicate that about 50% of the Tm-169 placed in the reactor can be converted with a flux of 10^{14} $n/cm^2 - s$ in about two months.

Natural thulia is available at about 3500 $/kg. After irradiation, the cost of the contained Tm-170 is estimated (Pacific Northwest Laboratory, 1973) to be 136,000 $/kg or about 10,000 $/$kW_{th}$. If a large number of m systems were desired, a demand would be created for thulium-170. A large and continuing demand for thulium-170 would ultimately lead to the need for a dedicated production facility.

The analyses show that the heat source can operate at a high temperature in concert with various power conversion systems. We give estimates of power system state points, performance, mass, and volume characteristics. Radiation analyses using the EGS radiation code provide a detailed assessment of shield requirements and allow optimization of the heat source material, which in turn affects the manner in which thulium-170 is produced. Heat transfer under normal and distressed conditions impacts the design of the shield. The heat source designs are well integrated in these respects.

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Nuclear Explosives Engineering Division (NEED)

This division supports a wide range of activities for Nuclear Design and Military Applications, as well as for high-pressure physics research. It provides the engineering design, analysis, and supervision of the fabrication and assembly of prototype nuclear explosives, and related physics experiments at the Nevada Test Site. Also related to these investigations is software development for analyses of complex engineering problems in solid mechanics, fluid mechanics, and heat transfer. NEED provides design, analysis, and testing of advanced, non-nuclear munitions for the Department of Defense.

For high-pressure gas handling systems, NEED provides expertise and has the capability to engineer systems with gas pressures up to 75,000 psi and fluid pressure up to 150,000 psi. The division also supports equation-of-state and hydrodynamic research for experimental physics programs in Livermore and Site 300.

UCRL-102715ABST

Recent Developments for Low Rate Impact and Metal Forming Analyses in the NIKE and PALM Codes

B. E. Engelmann

Analyses involving low rate impact and metal forming processes with large distortions require a robust, large deformation, finite element capability with good contact algorithms. The rapidly evolving NIKE codes are ideally suited for these types of problems. This paper will highlight new analysis capabilities developed at Lawrence Livermore National Laboratory, including rezoning, adaptive time step and solution strategies, and new constitutive models. The importance of thermomechanical coupling on forming processes will also be discussed in the context of a new coupled code, PALM2D. Incorporating a staggered step formulation, PALM2D was derived from NIKE2D and a nonlinear heat conduction code, TOPAZ2D. Numerical examples illustrating the performance and practical applications of the codes are presented.

UCRL-102716ABST

Recent Developments in DYNA3D for Impact Problems

R. G. Whirley

DYNA3D is an explicit, large deformation finite element code which is widely used for modeling complex impact problems. This paper opens with an overview of the current capabilities of DYNA3D. Next, several recent improvements to DYNA3D at Lawrence Livermore National Laboratory are described, including new constitutive models, a material model driver, slide surface improvements, and our ongoing work on shell elements. Current developments in graphical display of analysis results are shown. This paper closes with some practical examples illustrating the application of DYNA3D to real-world engineering problems.

UCRL-ID-104090

REMAP: A Computer Code that Transfers Node Information between Dissimilar Grids

A. B. Shapiro

REMAP is a computer code that transfers the axisymmetric, two dimensional planar, or three dimensional temperature field from one finite element mesh to another. The meshes may be arbitrary as far as the number of elements and their geometry. REMAP interpolates or extrapolates the node temperatures from the old mesh to the new mesh using linear, bilinear, or trilinear isoparametric finite element shape functions. REMAP is used to transfer the temperature field from a thermal analysis mesh to a more finely discretized structural analysis mesh when performing a thermal stress analysis. REMAP was designed to be used with the finite element heat transfer codes TOPAZ2D and TOPAZ3D, and the solid mechanics codes NIKE2D and NIKE3D. The

I/O formats in REMAP can be easily modified to accept input from other codes (e.g., finite difference) and generate output files for other structural codes. REMAP can be used to transfer any scalar field variable between dissimilar finite element meshes.

Three papers by Thompson (NASA), Lewis (GE), and Maffeo (GE) on the TRANCITS code were found useful in developing REMAP. Their idea of a coarse filter followed by a fine filter to determine which element from the old mesh contains a node point from the new mesh was used. The coarse filter determines a subset of elements from the old mesh that may contain the new node point. The fine filter determines the element that contains the new node point. REMAP uses the ray-surface intersection algorithm developed for the FACET code for the fine filter. This algorithm has the added capability to determine which element the node is closest to if the node point lies outside the perimeter (or surface) of the old mesh. Once an element from the old mesh has been identified as containing or closest to the new node point, the natural coordinates for the node point are calculated. The isoparametric finite element shape functions are calculated next. These shape functions are then used to interpolate or extrapolate the temperatures from the nodes comprising the old element to the new node point.

Chapter 2 contains information on preparing the input file and running REMAP. Example problems are presented in Ch. 3. The mathematical theory and numerical implementation are presented in Ch 4.

UCRL-JC-104826ABST

A New Elastoplastic Shell Element Formulation for DYNA3D

B. E. Engelmann and R. G. Whirley

Prepared for DYNA3D User Conference in Bournemouth, England, September 18–19, 1990.

The analysis of shell structures undergoing dynamic elastoplastic deformation is an important capability of DYNA3D. This paper presents an improved formulation for a four-node quadrilateral shell element for explicit dynamic analysis. The proposed element is [illegible]ived from a three-field weak form, and incorporates recently developed assumed strain methods for improved accuracy. In addition, the element is formulated in a large-displacement small-strain setting for minimum cost. Complex nonlinear constitutive models are easily incorporated into this formulation. Numerical examples illustrating the accuracy, robustness, and speed of the new element are shown.

UCRL-JC-104833ABST

Implementation of a Lamina-Based Constitutive Relationship for Analyzing Thick Composites

E. Zywicz

Prepared for *International Journal for Numerical Methods in Engineering.*

The finite element implementation of a lamina-based elastic constitutive relation appropriate for describing the three-dimensional behavior of fiber composite laminated media is presented. Unconstrained by the two-dimensional restrictions accompanying plate and shell theories, this approach resolves the macro three-dimensional deformation fields found in "thick" composites without requiring each lamina to be individually discretized to assign material properties. In rectangular isoparametric solid elements where laminae parallel an element "face," the implementation represents "exactly" the elastic laminate behavior by replacing the discrete lamina stiffnesses with continuous polynomial moduli functions. Attributable directly to the lamina relationship used and appropriate for fiber-dominated systems, the implementation automatically preserves interlaminar continuity of tractions and displacements within each element for laminates assembled from a single lamina type. The order of the effective moduli functions is determined by the element kinematics and by requiring identical net mid-surface elemental forces and moments. In general, this representation substantially reduces the number of stored variables and through-thickness integrations required, and allows "exact" integration by higher order

Gaussian quadrature. Additionally, a single element may span any portion or number of lamina, thus allowing nearly arbitrary meshing and solution resolution. Several numerical examples using three-dimensional eight-node isoparametric solid elements demonstrate the convergence and overall behavior of this approach.

UCRL-JC-104837ABST

Supercomputing and Nonlinear Seismic Structural Response of Freeway Structures

G. L. Goudreau, D. A. Schauer, D. B. McCallen, G. J. Kay, and R. W. Logan

Prepared for ASCE Structures Congress '91, Session: Inelastic Analysis and Behavior of Joints in Reinforced Concrete Structures, Indianapolis, Minnesota, April 29–May 1, 1991.

The Loma Prieta earthquake stimulated substantial reassessment of critical facilities and freeway structures in California, especially in the San Francisco Bay Area. Subsequent updates of seismological predictions indicate severe earthquakes are much more likely than previously thought. As the safety margins of existing structures are eroded by upgraded threats, simple design models of structural response prove inadequate. Nonlinear time-history response analysis is essential to understand the likelihood of structural collapse and threat to life. The supercomputers of the Lawrence Livermore National Laboratory, incorporating the latest structural response computer programs, were paired with the University of California's research on reinforced concrete damage to address this problem.

Preliminary studies of the Cypress freeway Loma Prieta response and test section experiments have led to further studies of retrofit options for other old state freeway bridges. Whereas standard design of freeway bridge structures is based on beam model analysis, we use the three-dimensional continuum modeling capability of our DYNA and NIKE codes, including plate and beam element modeling as appropriate. These unique tools provide the ability to model the external reinforcing of banded or welded plates on the outside of older concrete bents (especially the vulnerable joint region). Both static and dynamic simulation of local joint detail are assessed. Both elastic and damage accumulation concrete models are evaluated. Preload of reinforcing and retrofits are included. An essential part of this effort is the development of concrete/rebar modeling techniques that simulate actual concrete damage and rebar pullout behavior.

There are a number of unresolved issues which arise when modeling typical bridge structures. Idealization of the interaction between the bridge structure, soil mass, and bridge foundation is particularly difficult. Measured responses of a number of bridges during actual earthquakes have indicated that significant pounding occurs at the bridge abutments when thermal expansion gaps exist. Pounding can significantly change the response of the bridge relative to the analytical response which is predicted when pounding is neglected. The large-scale numerical simulation capabilities available at LLNL are well suited for a detailed parametric study aimed at identifying the important factors in bridge/soil-foundation interaction. The unique slide surface contact algorithms incorporated in the NIKE3D finite element program allow a rigorous treatment of the nonlinear contact problem at the bridge abutment. In addition, the supercomputer resources available at LLNL allow us to model the bridge superstructure in unprecedented detail.

UCRL-JC-104965ABST

A New Shell Element Formulation for Explicit Impact Analysis

B. E. Engelmann and R. G. Whirley

Prepared for inclusion in the book *Computational Aspects of Impact and Penetration*.

The analysis of shell structures undergoing dynamic impact is an important part of modern engineering design. This paper presents a new formulation for a four-node quadrilateral shell element for explicit dynamic analysis. The proposed element is derived from a three-field weak form and incorporates recently developed assumed strain methods for improved accuracy.

In addition, the element is formulated in a large-displacement small-strain setting for minimum cost. Complex nonlinear constitutive models are easily incorporated into this formulation. This new element has been implemented in fully vectorized form in the LLNL explicit finite element code DYNA3D. Numerical examples illustrating the accuracy, robustness, and speed of the new element are shown.

UCRL-MI-104966

Recent Developments in the DYNA and NIKE Codes at LLNL

R. G. Whirley

Prepared for DYNA3D User Conference in Bournemouth, England, September 18–19, 1990.

Viewgraph presentation.

UCRL-JC-105240ABST

Recent Developments in DYNA3D for Impact and Sheet Forming Analysis

R. G. Whirley and B. E. Engelmann

Prepared for *First National Congress on* Computational Mechanics, Chicago, Illinois, July 21–24, 1991.

Explicit analysis codes have been applied to problems involving large-scale impact for many years. Recently, many of these same codes have been adapted to model sheet forming processes. DYNA3D, a public domain explicit finite element code developed at Lawrence Livermore National Laboratory, has been widely applied to these problems. These simulations often involve extensive contact and thin metallic plates or shells. Accurate material modeling, robust contact algorithms, and stable shell elements are important for the effective solution of this class of problem.

This report summarizes several developments which extend the applicability of DYNA3D for impact and metal forming applications. A vectorized algorithm for anisotropic elastoplastic shell material models is presented. Ongoing research efforts in improved contact algorithms are highlighted, including experiences with augmented Lagrangian techniques. The new YASE shell element is briefly described. This element is accurate and highly resistant to hourglassing typically present in impact and sheet forming problems. Several large-scale numerical examples are presented to illustrate these new analysis capabilities.

UCRL-JC-105241ABST

Adaptive Solution Methodologies for Nonlinear Finite Element Analysis

B. E. Engelmann and R. G. Whirley

Prepared for *First National Congress on* Computational Mechanics, Chicago, Illinois, July 21–24, 1991.

The solution of severely nonlinear quasi-static boundary value problems presents a formidable challenge to general purpose finite element software. Many contemporary problems of interest, such as metal-forming simulation and severe structural response analysis, contain strong nonlinearities including material inelasticity, large deformations, and contact. These problems are best solved using an incremental implicit solution procedure. Over each increment, the nonlinear problem is typically linearized and solved using an iterative algorithm. The development of efficient and robust procedures for this incremental solution has been the subject of much research in recent years.

Recent work at LLNL has considered the evolution of an optimal incremental solution strategy. This includes selection of the iteration algorithm (quasi-Newton, modified Newton), increment size, and adaptivity criteria. This paper describes some recent results on adaptive solution strategies developed for the LLNL implicit finite element code NIKE2D. To facilitate this investigation, a solution strategy language has been developed: ISLAN2D—Interactive Solution Language for an Adaptive NIKE2D. This language allows flexible control of the solution strategy evolution and permits both parameters and algorithms to evolve adaptively during the solution process. This has been shown to yield a significant increase in robustness while decreasing computational cost. Essential aspects of this procedure are described and several numerical examples are presented.

UCRL-MA-105259ABST

DYNA3D Example Problem Manual

S. C. Lovejoy and R. G. Whirley

This manual describes in detail the solution of ten example problems using the explicit nonlinear finite element code DYNA3D. The sample problems include solid, shell, and beam element types, and a variety of linear and nonlinear material models. For each example there is first an engineering description of the physical problem to be studied. Next, the analytical techniques incorporated in the model are discussed and key features of DYNA3D are highlighted. INGRID commands used to generate the mesh are listed and sample plots from the DYNA3D analysis are given. Finally, there is a description of the TAURUS post-processing commands used to generate the plots of the solution. This set of example problems is useful in verifying the installation of DYNA3D on a new computer system. In addition, these documented analyses illustrate the application of DYNA3D to a variety of engineering problems. This manual should be helpful to new analysts getting started with DYNA3D.

UCRL-MA-105268

NIKE3D—A Nonlinear, Implicit, Three-Dimensional Finite Element Code User's Manual

B. N. Maker, R. M. Ferencz, and J. O. Hallquist*

This report provides a user's manual for NIKE3D, a fully implicit three-dimensional finite element code for analyzing the finite strain static and dynamic response of inelastic solids, shells, and beams. Spatial discretization is achieved by the use of eight-node constant pressure solid elements, two-node truss and beam elements, and four-node membrane and shell elements. Contact-impact algorithms permit gaps, frictional sliding, and mesh discontinuities along material interfaces. Simultaneous equations are solved either iteratively, using an element-by-element method, or directly (bandwidth minimization optional).

*Y Division, LLNL.

UCRL-MA-105401

TAURUS: An Interactive Post-Processor for the Analysis Codes NIKE3D, DYNA3D, TOPAZ3D, and GEMINI

T. E. Spelce and J. O. Hallquist*

This report provides an update to the user's manual for the TAURUS finite-element analysis post-processor. TAURUS is designed for use with the family of nonlinear finite element codes, DYNA3D, NIKE3D, and TOPAZ3D developed in the Methods Development Group at LLNL and the structural analysis code GEMINI. Taurus provides the ability to display deformed geometries and contours of a large number of quantities on meshes consisting of plate, shell, and solid elements. In addition, TAURUS can compute a variety of strain measures, reaction forces along constrained boundaries, and momenta. TAURUS is operational on a wide variety of platforms from supercomputers to workstations.

*Y Division, LLNL.

UCRL-MI-105404

INGRID: Three-Dimensional Preprocessing

B. N. Maker

Prepared for INGRID course to be given at the Dallas Supercollider Laboratory, Dallas, Texas. November 14–16, 1990.

Viewgraph presentation covering historical background, overview of capabilities, components of an INGRID model, and examples.

UCRL-MI-105405

TAURUS: An Interactive, Color, Three-Dimensional Postprocessor

B. N. Maker

Prepared for TAURUS course to be given at the Dallas Supercollider Laboratory, Dallas, Texas, November 14–16, 1990.

Viewgraph presentation covering history of TAURUS, summary of capabilities, examples of TAURUS in action, and hands-on experience.

UCRL-MI-105406

Thermo-Mechanical and Electro-Mechanical Finite Element Analysis with NIKE2D

P. J. Raboin

Prepared for NIKE2D course to be given at the Dallas Supercollider Laboratory, Dallas, Texas, November 14–16, 1990.

Viewgraph presentation covering NIKE2D thermal options, thermal material models, magnetic body force analysis, and an example problem.

UCRL-MI-105412

Introduction to the NIKE2D Code

P. J. Raboin and B. E. Engelmann

Prepared for NIKE2D course to be given at the Dallas Supercollider Laboratory, Dallas, Texas, November 14–16, 1990.

Viewgraph presentation following the layout of the NIKE2D manual. The introduction, overview of theory and capabilities, analysis, and input file creation are covered.

UCRL-MI-105649

A Discussion of Speed and Accuracy in the 1988 Sheet Forming Benchmark

R. W. Logan

Prepared for 4th IMOG Metal Forming Modeling Subgroup Meeting, GE-Neutron Devices Department, Largo, Florida, December 4–6, 1990.

Viewgraph presentation discussing investigator participation in a 1988 sheet forming benchmark.

UCRL-MI-105657

Finite Element Failure Analysis of 21-6-9 Stainless HERF Forgings

R. W. Logan

Prepared for 4th IMOG Metal Forming Modeling Subgroup Meeting, GE-Neutron Devices Department, Largo, Florida, December 4–6, 1990.

Viewgraph presentation including a problem, solution, and example of the predictive capability for metal forming analysis.

UCRL-MI-105759

An IMOG-MFM Benchmark Proposal

P. J. Raboin

Prepared for 4th IMOG Metal Forming Modeling Subgroup Meeting GE-Neutron Devices Department, Largo, Florida, December 4–6, 1990.

Viewgraph presentation covering member analysis of upset forging problems and results followed by comparisons of submitted results, a mean set of solutions, and a summary report.

Energy Systems Engineering Division (ESED)

This division provides mechanical and optical support to the Laser Program in five major program elements: Special Isotope Separation (SIS), Uranium Atomic Vapor Laser Isotope Separation (U-AVLIS), Inertial Confinement Fusion (ICF), Laser Technology, and Advanced Applications (AA). Working with program scientists, the ESED engineers, designers, coordinators, and technicians provide optical and mechanical components, analysis, and systems for these projects.

UCRL-102546

Design and Fabrication of High Damage Threshold Turning Mirrors for the Nova Laser

C. R. Wolfe, M. R. Kozlowski,* F. T. Marchi, F. Rainer, and E. Enemark†

Prepared for Optical & Optoelectronic '90 SPIE, San Diego, California, July 8–13, 1990.

Laser induced damage to optical components severely limits the operating fluence of high peak power lasers used for fusion research such as the Nova laser at the Lawrence Livermore National Laboratory. In particular, surfaces and optical thin films often damage at a lower fluence than bulk materials in large aperture, high quality optics. We have designed and are fabricating new 94-cm turning mirrors for Nova as part of the "Precision Nova" program to improve beam quality. A new design has been optimized for updated optical performance specifications including increased damage resistance. The new mirror design will operate at all turning angles required by the ten Nova beamlines. This flexibility reduces mirror inventory and fabrication cost. A process of "conditioning" the mirror coating has been developed that is permanent and increases the damage threshold by as much as a factor of 2 or 3.

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UCRL-102941

Four-Frame Gated Wolter X-Ray Microscope

R. J. Ellis, J. E. Trebes,* D. W. Phillion,* J. D. Kilkenny,* S. G. Glendinning,* J. D. Wiedwald,† and R. A. Levesque*

Prepared for Eighth Topical Conference on High Temperature Plasma Diagnostics, Hyannis, Massachusetts, May 6–10, 1990.

A four-frame, gated x-ray microscope has been developed for the study of inertial confinement fusion. Four x-ray images were obtained by introducing flat, grazing-incidence mirrors into the converging annular ray-bundle of a previously developed Wolter x-ray microscope system. Gated microchannel plate detectors and associated drive electronics were developed which can record a sequence of gated images of less than 100 ps duration, with an interframe timing accuracy of ±50 ps. The resulting diagnostic can record one time-resolved image and four gated images simultaneously. The system is described, and images of an imploding capsule are presented which demonstrate the instruments unique capabilities.

*Y Division, LLNL.
†Laser Engineering Division, Electronics Engineering, LLNL.

UCRL-JC-103337ABST

Cascade and Hylife ICF Reactor Concept Revisions

J. H Pitts, R. O. Bangerter,* R. W. Moir,† and M. Tabak*

The Cascade and HYLIFE-II inertial-confinement-fusion (ICF) reactor concepts incorporate a renewable first wall and blanket that produces tritium, acts as a heat-transfer medium, and protects the reactor structural wall by reducing stress levels and radiation damage. Cascade uses a flowing granular blanket, made mainly of $LiAlO_2$ but with a BeO neutron multiplier and carbon at the inner surface. The blanket is held against the structural wall by rotation of the reactor. HYLIFE-II includes a jet array made of molten Flibe salt.

Heavy-ion-beam drivers should efficiently couple their energy to fusion fuel pellets with illumination geometries restricted to two cones having half angles of ~10°—an acceptable geometry for both Cascade and HYLIFE-II. Laser-driver beams must be more uniformly spread over the surface of a unit sphere and are probably not compatible with either Cascade or HYLIFE in their present forms.

In Cascade, about a kilogram of material from the inner surface of the blanket is vaporized by each fusion pulse. This produces thermal stress in the inner carbon granules that could cause excessive breakage; furthermore, the vaporized carbon sublimes on all surfaces cooler than ~3900 K. We suggest including a sacrificial, solid-lithium x-ray and debris shield around each fuel pellet as it is injected into the Cascade reactor. Although the shield vaporizes, it extends the time of energy deposition in the blanket enough that no other vaporization occurs. Vaporized lithium is easily condensed on plates outside the reactor and recycled. In the absence of granule vaporization, shock waves that could cause granule breakage are eliminated.

Improved safety could result from using Flibe rather than liquid lithium as a blanket material in HYLIFE-II. We are evaluating the feasibility of an oscillating jet array that would protect the entire reactor from neutron damage (except for the regions used for driver beam transmission) and yet allow repetition rates up to 8 Hz.

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UCRL-JC-103377ABST

A Spindle Stage Refractometer for Single Crystal Optical Studies in the Visible and Near IR

L. E. Davis*

A spindle stage refractometer has been developed to measure the refractive indices of small single crystals for wavelengths of light between 360 and 1100 nm. Established methods from optical crystallography are used to orient a crystal on a spindle stage, and then match the refractive index to an immersion fluid. The refractive index of the fluid for the wavelength of light and matching temperature is determined from a reference crystal on a second spindle axis mounted in close proximity to the sample. The reference crystal is uniaxial and highly birefringent, and rotation of its position produces a continuous change in refractive index between n_e and n_o, its principal indices of refraction at the filtered wavelength of light. A charge coupled device (CCD) camera with a broad spectral response is coupled to one port of the microscope, and crystals are imaged on a television monitor using light sources from UV to IR.

A description of the apparatus and methods is given. Examples from our investigations of new optical crystals demonstrate the application and advantages of the instrument for determining refractive indices, birefringence, and optic axial angle for extended wavelength ranges.

*Condensed Matter & Analytical Sciences Div., Chemistry & Materials Science Dept., LLNL.

UCRL-ID-103911

Experimental Study of the Optical Constants of Metals at High Temperature

M. A. Havstad

The optical radiative properties of the surfaces of various metals at high temperature, below and above the melting point, are of importance to a wide range of research and development activities, including laser welding, metal refining, electron beam processing, vacuum arc remelting, and laser isotope separation. The optical radiative properties of high temperature metals influence the energy balance and heat transfer in such applications and thereby determine performance and economic viability. Thermal radiative properties are often vital input data for heat transfer computations performed during development of a process. The accuracy of the input data determines the results of calculations that provide the understanding needed to make design changes and successfully complete development.

This study is unusual among measurements of thermal radiative properties in four respects. First, surface conditions have been controlled and measured with extreme care. Second, two independent measurement systems are used to allow error estimates to be checked. Third, general measurement methods have been applied over much wider parameter ranges than previously used. Ellipsometry is a powerful general method because it yields a basic material property, the complex refractive index, from which other radiative properties can be calculated. Here, it has been applied over a wide spectral range with high temperature samples. Fourth, the search for general measurement methods led us to carry out a more complete evaluation of the sensitivity of potential measurement techniques than had been reported to date.

UCRL-JC-104555ABST

Large Aperture (80-cm diam) Phase Plates for Beam Smoothing on Nova

B. W. Woods, I. M. Thomas,* M. A. Henesian,* S. N. Dixit,† and H. T. Powell*

Prepared for OE/LASE '91, Los Angeles, California, January 20–25, 1991.

We have designed, fabricated, and tested 80-cm-diam distributed phase plates (DPP) to be used at 527 nm for smoothing the Nova laser in the far field. These phase plates consist of a spatially random two-dimensional pattern of bi-level hexagonal elements which introduce a relative phase delay of 0 or π. Fabrication of DPPs involves vapor deposition of SiO_2 onto a photoresist-patterned UV grade fused silica substrate followed by a liftoff technique to create the 0-phase delay areas. A sol-gel antireflective coating is then applied to the DPP using a dip coating process. We discuss DPP coating requirements and coating details.

We have measured and analyzed the near-field intensity pattern produced by DPPs and have seen spikes as large as 4 to 1 produced by diffraction from the phase steps. As a result, on the Nova laser system, we have chosen to locate a DPP as the last optical element in the laser chain to minimize the threat of optical damage to beamsplitters, focussing lenses, etc. For simplicity, we have elected to fabricate DPPs at the 80-cm size to replace the existing target chamber debris shields. We discuss off-line characterization of the DPPs which includes phase stepping interferometry, spectroscopy, and near- and far-field beam profiling. We are also performing target experiments on Nova using one beam that is outfitted with a DPP. A full aperture splitter sends a portion of this beam into a precision "on-line" laser diagnostics platform that was outfitted with a duplicate DPP where we measure far-field intensity distribution. The DPP properties are characterized by far-field and quasi-far-field diffraction patterns in terms of the spatial Fourier distribution of intensities. We compare the measured performance of the DPPs with the calculated characteristics.

We also present alternative DPP fabrication ideas that scale readily to large diameters.

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UCRL-JC-105665ABST

Modeling of a Dissolution System for Transuranic Compounds

Z. Chiba and C. G. Dease*

Prepared for AIChE 1991 Summer National Meeting, Pittsburgh, Pennsylvania, August 18–21, 1991.

A system has been built for dissolution of transuranic compounds for separation and recovery from scraps and other waste. The system consists of a flowthrough annular electrochemical cell to generate AgII from a solution of silver nitrate and nitric acid. The solution from the cell is partially diverted into a dissolver containing particles of transuranic and other insoluble compounds. The transuranic compounds are dissolved on reaction with AgII. The flow rates and temperatures in the main flow loop (comprising the cell) and the dissolver flow loop

(containing the particulates) can be independently controlled and varied. A model has been developed to predict the behavior of the system under different operating conditions with a view to optimizing system performance. Models of generation of AgII in the electrolytic cell and parasitic removal of AgII by water reactions are included in the systems model.

The model has been exercised for two limiting cases of transuranic particle sizes corresponding to the initial and final phases of the dissolution process. In the first case, where there are a large number of fine particles, all of the AgII delivered to the dissolver reacts with the particles. In this case, it is advantageous to operate the main loop at the highest possible flow rate and the highest possible temperature. The flow diverted to the dissolver loop must be above a certain fraction of the main loop flow for high-efficiency operation.

In the second case, where a smaller number of coarse particles remain in the dissolver, a high concentration of AgII is desirable. In this case, lower cell temperatures are indicated. The influence of the main loop flow rate is not very strong on the dissolver AgII concentration. However, the dissolver flow rate must be maintained above a certain minimum both to maintain high AgII concentrations and to assure adequate suspension and dispersal of particles in the dissolver. The model also predicts the optimal strategy for varying the system temperature to maintain maximum AgII concentration from startup through the end of the batch cycle.

A plant scale experimental dissolution system assembled at LLNL has recently become operational. It is currently undergoing testing with surrogate materials. Test results are described and compared with model predictions.

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Weapons Engineering Division (WED)

This division is responsible for mechanical engineering support of nuclear weapons development, production, and maintenance of an important portion of the modeling of advanced weapons concepts. It maintains active support of weapons safety studies, and investigates new technologies for weapons control.

WED activities involve new weapon development, computer modeling and analysis, environmental testing, initiation systems development, and weapons technology development. WED works in close cooperation with DOE and DOD on weapons production and stockpile surveillance.

UCRL-102680ABST

Near-Term Warhead Enhancement for Mk48 ADCAP—An Insertable Nuclear Component

J. E. Kervin, J. G. Newman,* and J. W. White†

Prepared for Submarine Technology Symposium, Johns Hopkins University, May 8–10, 1990.

This paper investigates a possible near-term warhead enhancement for the Mk 48 ADCAP, a very low yield insertable nuclear component (INC). An INC is a concept in nuclear weapon design in which not all of the components required for the nuclear weapon are stored in the delivery vehicle. For this particular system, the torpedo without the INC installed would still have a near normal conventional capability. This paper explores the possible explosive power available with such a weapon and what that translates to as far as increased warhead lethality is concerned. It develops how such a system might be incorporated into an Mk 48 ADCAP warhead with minimal impact on the conventional warhead and finishes with the possible implications to the Navy.

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UCRL-CR-104574ABST

Design of a Triaxial Residual Stress Measurement System Using High Energy X-Ray Diffraction

J. F. Shackelford,* B. D. Brown,* and F. S. Park

Previous design studies for UC/LLNL in developing concepts for residual stress measurement in engineering materials have been extended. A pre-prototype energy dispersive x-ray diffraction (EDXRD) system has been fabricated at UCD. A 300 kV radiography source is used in conjunction with an intrinsic germanium detector and a MacII/LabVIEW data acquisition system. Specimens up to 25 mm equivalent steel thickness (and one meter gross dimensions) can now be evaluated. The pre-prototype system serves as the hard x-ray, bulk stress measurement component of the previously reported hybrid stress measuring system (which would include a traditional multi-angle surface measurement system using soft x-rays). In addition, a detailed study of residual stress analytical equations has been completed and applied to various metallic and ceramic materials. During the grant period, related studies were completed on stress measurement using synchrotron radiation and on a critical review of the residual stress literature.

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Engineering Sciences Division (ESD)

This division provides complete technical services to LLNL programs for materials characterization, measurements engineering, nondestructive evaluation, and mechanical systems design and evaluation. ESD provides mechanical design and analysis to the Chemistry and Materials Science Department, as well as a number of other organizations. The division has more than 20 separate laboratories and facilities that are organized into sections responsible for specific technology areas.

ESD maintains the Engineering Records Center which reproduces, distributes, and stores engineering drawings for LLNL's Mechanical, Electrical, and Plant Engineering Departments.

UCRL-102345

Computerized Tomography of High Explosives

H. E. Martz, D. J. Schneberk,* G. P. Roberson, S. G. Azevedo,† and S. K. Lynch‡

Prepared for 4th International Symposium on Nondestructive Characterization of Materials, Annapolis, Maryland, June 11–14, 1990.

Computerized tomography (CT) techniques are being investigated to improve the current manufacturing process flow of high explosives (HE). In order to revise the manufacturing process flow, it must be demonstrated that CT can provide information comparable to the techniques currently used:

1. Shadow graphs to determine gross outer dimensions.
2. Radiography to detect cracks, voids, and foreign inclusions.
3. Dye penetrant to identify surface cracks.
4. A wet/dry bulk-density measurement technique.
5. Destructive core sampling for exhaustive density measurements.

To meet this objective, a series of CT experiments has been designed and was divided into three phases. The Phase I experiments are discussed. Application of x-ray CT could significantly improve safety and greatly reduce the process-flow time and costs, since CT could simultaneously determine rough outer dimensions, bulk density, density gradients, and the presence of cracks, voids, and foreign inclusions within HE.

Until now, x-ray CT studies of HE materials have resorted to a study of mock-HE materials, i.e., polymeric materials whose x-ray attenuation is similar to, but not the actual material. In this paper, our unique HE operational capability and laboratory-built CT scanners are used to study actual PBX9502 high explosives and mock HE. In the next section, the PBX9502 chemical components and manufacturing process flow are discussed. The scans performed and discussion of results are given in the CT Experiments and Results and Discussion sections. In the conclusion, the CT results presented here are related to the typically used HE investigation techniques mentioned above.

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UCRL-102520ABST

Material Characteristics Related to the Fracture and Particulation of Electrodeposited-Copper Shaped Charge Jets

D. H. Lassila

Shaped charges with two different types of electrodeposited-copper liners have been found to produce fragmented and particulated jets of poor quality. Results of tensile testing and chemical analysis of fracture surfaces of these materials show that segregated impurities cause grain boundary embrittlement (loss of ductility) under tensile loading. Increase in the embrittlement occurs with increase in test temperature over some temperature ranges. Good correlation between the fracture behavior and chemical analysis of the fracture surfaces of the materials and the degree of jet fracture and particulation is observed. This correlation suggests fracture and particulation of the shaped charge jets is primarily due to the segregated impurities in the electrodeposited materials. Results of the study suggest tensile testing at elevated temperature can be used to screen liner materials for optimum performance.

UCRL-JC-103315ABST

Material Characteristics Related to the Fracture and Particulation of Copper Shaped Charge Jets

D. H. Lassila

Shaped charges with different types of electrodeposited copper liners have been found to produce fragmented and particulated jets of poor quality. By comparison, jets of OFE copper exhibit high elongation before undergoing ductile failure. Results of tensile testing and Auger electron spectroscopy analysis of fracture surfaces of each of these materials show that segregated impurities cause grain boundary embrittlement (loss of ductility) under tensile loading. Increase in the embrittlement occurs with increase in test temperature over some temperature ranges. Good correlation between the fracture behavior and chemical analysis of the fracture surfaces of the materials, and the degree of jet fracture and particulation is observed. This correlation suggests fracture and particulation of the shaped charge jets is primarily due to the segregated impurities in the electrodeposited materials. Results of the study suggest tensile testing at elevated temperature can be used to screen liner materials for optimum performance.

This laboratory analysis has been applied to the ETP copper used by Duffy and Golaski (BRL) in their well-known study of the effect of grain size on jet penetration. The annealing process used by Duffy and Golaski to control grain size also is shown to produce impurity concentrations at grain boundaries. The increase in impurities at grain boundaries which accompanies the grain size growth promotes the brittle fracture mode and provides an alternate mechanism for decreasing the observed jet performance as grain size increases. Additional experiments are recommended where grain size variation is achieved independent of grain boundary impurity concentrations.

UCRL-JC-103326ABST

Localized Wave Transport of Pulsed Beam Energy

D. K. Lewis, W. D. Cook,* and R. W. Ziolkowski†

Prepared for Symposium on Physical Acoustics Fundamental and Applied, Kortrijk, Belgium, June 19–22, 1990.

The representation of a bounded beam as a plane wave is often an inadequate description in a scattering interaction. Much work has been put into identifying better descriptions of beams, and some remarkable new results have been developed. One is the localized wave transport (LWT) representation.

The most notable traits of the LWT are the maintenance of beam width for distances much longer than the equivalent continuous wave Rayleigh distance, as well as improved localization of energy in the beam, and maintenance of spectral width in the pulses over those same distances.

These improvements come at the expense of increased complexity in launching the pulses. The array must be driven with different input signals at different array locations. This requires individually addressable array elements as well as many different driving circuits.

Recent acoustic experiments have confirmed the predicted properties of these pulses. An overview of the theory is given, and experimental methods and results to date are presented.

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UCRL-JC-103469ABST

High Strain Rate Deformation Behavior of Shocked Copper

D. H. Lassila, M. M. LeBlanc, and G. T. Gray III*

Prepared for International Conference on Shockwave and High Strain Rate Phenomena in Materials, San Diego, California, August 12–17, 1990.

Uniaxial mechanical testing of shock-prestrained copper was performed over a range of strain rates from 10^{-3} to 7×10^3 s^{-1} in tension and compression to study the effects of a shock-induced substructure on constitutive behavior. For comparison, copper in the preshocked condition (annealed, 15 μm grain size) was also tested. Results of the study show that the post shock mechanical behavior of copper at high strain rates is similar to that previously reported at slow strain rates, i.e., the shocked copper had an increase in yield strength and a decrease in work hardening rate. The strain rate sensitivity of the shocked copper was found to be similar to that of the unshocked material. Tensile test results for both high and low strain rate tests are presented and show the elongation of the shocked material to be considerably less than that of the unshocked material. The effects of the constitutive behavior of the shocked and unshocked materials on elongation are discussed.

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UCRL-JC-103528ABST

Ductile-Brittle Transition Temperatures of CVD and Forged Tungsten

D. H. Lassila

Three point bend tests were performed on samples of tungsten fabricated in two ways:

- Chemical vapor deposition (CVD).
- Powder metallurgy procedures followed by forging at elevated temperature below the recrystallization temperature.

Testing was performed under a vacuum of 10^{-5} Torr at temperatures ranging from 22°C to 1000°C. Results of these tests were used to determine ductile-brittle transition temperatures for the various products. Auger electron spectroscopy was used to determine impurities present at the grain boundaries of CVD products that are believed to be occluded in the material during vapor deposition and give rise to brittle behavior at low temperatures.

UCRL-JC-103761ABST

Estimation of Geometrical Parameters in Parallel-Beam, Fan-Beam, and Cone-Beam CT Systems

S. G. Azevedo,* D. J. Schneberk,† J. P. Fitch,‡ H. E. Martz, M. F. Skeate,§ and G. P. Roberson

Prepared for 1990 QNDE Conference.

Computed tomography (CT) scanners produce accurate and quantitative reconstructed images only if the scan geometry is accurately discerned. This geometry is communicated to the image reconstruction algorithms by certain parameters—e.g., rotational center, detector midline location, magnification, etc. Small errors in these parameters can cause severe distortions or artifacts in the reconstructions. At the same time, it is difficult to assign or measure these parameters accurately enough for some high-resolution in-house-assembled x-ray and proton CT scanners. In this paper, we describe an efficient method for accurate calculation of the parallel-beam center-of-rotation or protection center, without need for a calibration scan. This method uses all the data in the sinogram to estimate the center by a least squares technique and requires no previous calibration scan. The method also finds the object center-of-mass without reconstruction of its image. Since it uses the measured data, the method is sensitive to noise in the measurements, but that sensitivity is relatively small compared to other techniques. Examples of

its use on simulated and actual data are included. We also show why fan- and cone-beam geometry parameters cannot be estimated only from the sinograms, but require a calibration scan. Methods for estimating these parameters from the calibration scan are also shown.

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UCRL-JC-103762ABST

Multiple-Energy Techniques in Industrial Computerized Tomography

D. J. Schneberk,[*] H. E. Martz, Jr., S. G. Azevedo,[†] and M. F. Skeate

Multiple-energy CT scans enable the calculation of effective-Z, component saturation, and density images. A number of specific multiple-energy techniques have been developed for medical applications and are in use at this time. It is not clear that these techniques can be used for industrial CT (ICT) applications without modification since the range of materials in ICT is much larger, both across the objects of interest and within a particular object. The CT Group at LLNL has developed various multiple-energy CT techniques and applied them to the study of different objects. These techniques make use of current tabulated x-ray cross sections and models of x-ray tube spectra. It is our opinion that these techniques have a much wider range of application than techniques employed in medical scanning. We will show calculated effective-Z, component saturation, and density images for an aluminum-lexan phantom, high explosive material samples, and a three phase (air, water, and oil) simulated soil sample acquired using isotopic and/or x-ray tube sources.

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UCRL-JC-104101ABST

Application of Diffraction and Modeling to Determine Residual Stress

E. C. Flower

Prepared for 1990 TMS Fall Meeting, Detroit, Michigan, October 7–11, 1990.

Accurate measurement of residual stress in structural components is often a difficult task. A technique widely used in the design of structural components is the finite element method (FEM) that provides values of stress and strain which develop from external loads. This method shows promise to aid in the determination of residual stress, but first must be shown valid for simple stress states. Residual strains in well-characterized metal specimens were measured with neutron diffraction, x-ray, and synchrotron radiation, and results compared to calculations made with the finite element method. Techniques to relate measured strains to stress are discussed. Data is presented in terms of the choice of diffraction line and the effect of elastic anisotropy and texture on the results.

UCRL-JC-104107ABST

X-Ray Optics for Scanning Fluorescence Microscopy and Other Applications

R. W. Ryon, R. A. Day, T. W. Barbee,[*] and P. J. Biltoft

Prepared for Pacific Conference on Chemistry and Spectroscopy, San Francisco, California, October 31–November 2, 1990.

We are developing x-ray optics for imaging by x-ray fluorescence and for other applications where the increased radiation flux from focused x-rays is needed. The principal technique we are

using is Kirkpatrick-Baez (K-B) mirror optics. This system uses two curved mirrors mounted orthogonally to each other along the optical axis. The first mirror provides vertical focus; the second mirror provides horizontal focus. Diffracting mirror surfaces are produced by coating with alternating layers of high and low electron density materials with interlayer spacings as low as 1 nm. An objective of our work is fluorescence imaging with resolution in the 1- to 10-μm range using x-rays with energies of approximately 20 keV. The imaging technique is analogous to scanning electron microscopy. At present, we use spherical surfaces because they are readily available. We are working toward obtaining aspheric substrates in order to eliminate spherical aberrations which distort the focus of the beam. Recently obtained images are shown, and future directions are indicated.

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UCRL-JC-104187ABST

Nuclear-Spectroscopy-Based, First-Generation, Computerized Tomography Scanners

H. E. Martz, G. P. Roberson, D. J. Schneberk,* and S. G. Azevedo†

Prepared for 1990 IEEE Nuclear Science Symposium, Arlington, Virginia, October 23–26, 1990.

We built a number of inexpensive, nuclear-spectroscopy-based, first-generation, computerized tomography (CT) scanners to satisfy most Lawrence Livermore National Laboratory (LLNL) CT inspection requirements. We describe these CT scanners in detail and discuss their advantages and disadvantages when compared to the more common, higher-generation, current-integration-based scanners. The major advantage of nuclear-spectroscopy-based scanners is that they can be used to determine an internal, spatially distributed, effective-atomic-number and density map within the object. We also show how these scanners can be used to acquire meaningful chemical information for nondestructive characterization of materials and dimensional information for evaluating assembled components.

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UCRL-JC-104194ABST

Evaluation of Cylindrical Shear Joints for Composite Materials

S. E. Groves, D. R. Lyons,* F. H. Magness, and R. J. Sanchez

Prepared for *Journal of Composite Materials.*

The objective of this work was to evaluate the strength of four candidate cylindrical shear joints for composite tubes. The basic design for the joint entails an axial length of 1 in. with an external 15° tapered cone. The purpose of the joint is to transfer axial load from a cylinder through a steel shear attachment with a matching internal conical seat. The design candidates consisted of a bonded wedge cone, pinned wedge cone, and a bonded and pinned wedge cone attached to a 2-in.-diam composite tube and a wedge cone integrally wound into the tube. The actual joint strengths achieved were higher than expected for some designs and were found to be dependent on the amount of hydrostatic or radial compression applied to the joint. The bonded wedge ring and the integral wedge ring both achieved over 96 MPa (14 ksi) of shear strength without failure. Due to the unexpectedly high shear strengths of the joints, most of the failures were located in other parts of the test specimen. The bonded wedge cone was probably close to its maximum load carrying capacity while the integral wedge design showed potential for even higher shear strengths. The bonded and pinned joint reached a peak shear strength of 78.9 MPa (11.5 ksi) and the pinned only configuration achieved 70.6 MPa (10.3 ksi). When loaded without any hydrostatic compression, the joint strengths were less than 34.3 MPa (5 ksi); however, the failure mode was hoop compression buckling of the tube itself as opposed to a joint shear failure.

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UCRL-JC-104198

Computerized Tomography Studies of Concrete Samples

H. E. Martz, G. P. Roberson, M. F. Skeate, D. J. Schneberk,* and S. G. Azevedo†

Prepared for *Concrete International: Design and Construction.*

X-ray computerized tomography (CAT or CT) is a sophisticated imaging technique that provides cross-sectional views of materials, components, and assemblies for industrial nondestructive evaluation (NDE). We have studied the feasibility of using CT as an inspection tool for reinforced concrete and the use of multi-energy, linear attenuation techniques to deduce variations in density (ρ) and/or atomic number (Z) that could be caused by varying the types of concrete mixes and/or compaction in the concrete itself. To perform this study, we designed and built a prototype medium/high-energy (200- to 2000-keV) CT scanner—ZCAT—to image small concrete samples (≤30-cm diam, ≤75-cm high) with a spatial resolution of about 2 mm. We used ZCAT to quantitatively inspect a 20-cm concrete cube with 1.27-cm-diam reinforcing bars (rebars) and to measure ρ and/or Z variations in a 20-cm-diam concrete cylinder. We describe the ZCAT scanner design, some of its physical limitations, and the data-acquisition parameters used in our study. Our results and those of others show that CT can be used to inspect reinforced concrete and to distinguish material ρ and/or Z variations within concrete.

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UCRL-JC-104482ABST

Material Characterization Using Digitized Radiographs

J. J. Haskins and W. T. Fritts

Prepared for ASNT Topical Conference, Automating and Advancing Radiologic NDT II, Wilmington, Delaware, August 14–16, 1990.

Radiography is one of the most common and useful NDE techniques. Its usefulness, however, has been restricted because traditional radiographic interpretation is qualitative. Transformation of the image data into the digital domain now allows us to both interpret quantitatively and to improve the quality of the image by removing image noise. A global rather than a point-by-point analysis is the key to this noise reduction and sensitivity improvement. Although significant advances have been made using empirical approaches, the key to future improvements lies in geometric modeling, mathematical analysis (MTF and PSF), and radiation transport calculations.

Traditional analog interpretation of radiographic images has been based on subjective viewing in the position/greyscale space. Each single greyscale value represents the summation of all of the image contributors. The success of the technique depends heavily on the unique capabilities of the human mind to interpret what it sees and the ingenuity and experience of the film readers.

Radiographic film is one of the highest density information storage media available. If we assume film grain clumping to be less than 0.0005 in. (12.5 microns) and information available over a range of film density from 0 to 4.0, then a 14-in. × 17-in. radiograph contains at least (14 × 2000) × (17 × 2000) × 12 = 11 gigabytes of data. Several options are currently available for converting the analog image into digital data. These include video camera based systems, scanning microdensitometers, and systems based on linear detector arrays.

There is obviously a diverse range of techniques which can be used to analyze digitized radiographic images. Results presented in this paper are primarily based on an empirical approach but other approaches are discussed.

Empirical approaches depend on *a priori* knowledge of noise sources and reference standards to improve the signal-to-noise ratio and to assign quantitative physical values to image data. The success of empirical approaches to noise reduction depends on the fact that many of the radiographic factors which produce noise in the image appear as slowly varying changes in film density with respect to position in the image. The heel effect from the x-ray tube produces gradual changes in film density from one side of the radiograph to the other. Part and facility scatter produce changes which are gradual with respect to position. A global analysis of the image allows us to determine the equation of the low frequency data curve and subsequently remove it mathematically. The result is a significant improvement in the signal-to-noise ratio. The signal that we are interested in normally involves only a small region of the position space and therefore is not affected by the global corrections. The use of reference standards in the radiographic image allows us to transform film density data into physical parameters such as density, thickness, or porosity. Including these standards in the radiograph minimizes the need for calculated corrections for physics phenomenon such as beam hardening.

More sophisticated analysis and correction of the image can be performed by utilizing our knowledge of radiation physics. Development of geometric models can be used for part geometry. Spatial parameters in the form of modulation-transfer functions or point-spread functions can be used to deconvolve the radiographic images. Use of radiation transport codes can be used to improve signal-to-noise ratio by removing the calculated effects of radiation scatter and secondary interactions which interfere with the desired transmission signal.

The material characterization results presented in this paper are based on images which are digitized using the Du Pont NDT Scan II digitizer with a pixel size of 70 microns and an array size of 5000 × 6000 pixels. This system produces a 59 megabyte image which, although not as large a data file as the original film, still presents a challenge in display and analysis. Examples include quantification of porosity variations smaller than 0.5%, demonstration of geometric modeling in quantifying density variations, and noise reduction through deconvolution of the image using a measured point spread function.

UCRL-JC-104580ABST

Localized Transmission of Acoustic Beam Energy

D. K. Lewis

Prepared for 1990 IEEE Ultrasonics Symposium, Honolulu, Hawaii, December 4–7, 1990.

Recent experiments have shown that it is possible to create a pulsed beam of acoustic energy which maintains amplitude and beam width better than either conventional single frequency or wideband beams of comparable frequency content. This presentation describes work done at LLNL in the design and generation of these localized wave transport beams.

The experimental techniques to date have included acousto-optics, two transducer linear superposition, and arrays composed of individually addressable elements. The beam width, amplitude, and frequency spectra of the localized beams are compared to those of both single frequency tone-burst piston beams and wideband Gaussian beams. An overview of the theory is given and proposed applications discussed.

UCRL-JC-104770SUM

A Systems Engineering Approach for Developing the Engineered Barrier System

D. J. Ruffner, J. A. Blink,* L. J. Jardine,† B. G. Morais, and M. A. Revelli‡

Prepared for 1991 International High-Level Radioactive Waste Management Conference, Las Vegas, Nevada, April 28–May 2, 1991.

Systems Engineering, a structured methodology that allows for organizing and documenting thought processes, has an engineering and a management function.

The engineering function translates the operational requirements into engineering functional requirements and subsequently expands those functional requirements into detailed design requirements. It involves: analyzing system performance requirements, synthesizing alternative design solutions, performing system level trade-off studies, and selecting the preferred configuration that best meets the system operational criteria.

The management function controls the total system development effort by achieving an optimum balance of all system elements. This function also provides the plans for managing, developing, and operating the system throughout its lifetime, and for controlling change.

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UCRL-JC-104824ABST

Viscoelastic Behavior of Elastomeric Membranes

W. W. Feng

Prepared for *Journal of Applied Mechanics.*

The formulation for large deformations of an axisymmetric nonlinear-plane viscoelastic membrane is developed. The solutions from the formulation for both creep and relaxation of a circular membrane are presented. An experiment that demonstrates the relaxation phenomenon was performed and the experimental data are used to determine the constitutive equation of an elastomer.

UCRL-JC-104825ABST

On the Finite-Strain-Invariant Failure for Composites

W. W. Feng and S. E. Groves

The finite-strain-invariant failure criterion, developed by Feng, is being evaluated with the experimental data for a boron/epoxy, symmetrically balanced, angle-ply laminate. The results indicate that the failure-criterion prediction agrees with the experimental data and that failure criterion also predicts matrix- or fiber-dominated modes of failure. Two special isotropic cases in infinitesimal strain theory are obtained. The failure criteria for these special cases preserve Von Mises yield criterion mathemathical forms—both generalized and in plasticity.

UCRL-JC-104829ABST

Computerized Tomography Assessment of Reinforced Concrete

H. E. Martz, D. J. Schneberk,* G. P. Roberson,† and S. G Azevedo‡

Prepared for 5th International Symposium on Nondestructive Characterization of Materials, Karuizawa, Japan, May 27–30, 1991.

The problem of determining the remaining life of old concrete structures, especially old bridges, is of utmost importance for the civil engineering infrastructure. Most bridge decks, short span bridges, and supporting structures for bridges (e.g., piers and spandrel beams) are made of concrete. None of the existing nondestructive testing methods for concrete are adequate, and there is a strong need for development of better techniques that permit the engineer to assess the remaining life of old structures with a satisfactory degree of precision. The nondestructive evaluation should provide information on location of reinforcing bars, degree of cracking in reinforcing concrete, state of corrosion, and depth of cover. X-ray computed tomography (CAT or CT) is an advanced imaging technique which provides three-dimensional nondestructive characterization of materials, components, and assemblies. We are investigating the use of CT technology to inspect and characterize concrete structures. The goals of this concrete CT study are to accurately determine location of reinforcing bars, degree of cracking in reinforcing concrete, state of corrosion, depth of cover, and provide a foundation for the further development of industrial CT systems.

As part of a collaborative effort with UC Berkeley, the CT group at LLNL is inspecting concrete samples using two different scanners. Proof-of-principle scans were performed with a laboratory-built prototype scanner, ZCAT. This scanner produced CT images with 2-mm spatial resolution over 20 cm. Multi-energy quantitative CT images of a reinforced concrete cube (20-cm per side) and a concrete cylinder (20-cm diam) were obtained. From a detailed analysis of the CT data, we found that the experimental and predicted concrete linear attenuation coefficient values for both the reinforced cube and the cylinder were well within experimental error at the three scan energies: 316, 468, and 604 keV. The rebar within the cube was clearly identified, as well as various size voids within the cube and cylinder. With respect to a filled concrete cylinder sample, we will demonstrate that CT can be used to obtain images of density and/or atomic number variations within concrete as well. On the basis of these results a scanner was built, MECAT, to improve both contrast and spatial resolution down to 0.5 mm. Using this scanner, we are performing CT experiments on three additional concrete samples. These samples are 20-cm-diam cylinders, two of which are reinforced. CT is being used to study the nonreinforced concrete cylinder as a function of loading to measure the size of cracks induced in the bulk sample. The two reinforced cylinders contain an axially aligned reinforcing bar. One

cylinder had corroded rebar. Rebar in the other cylinder was uncorroded. We used CT to distinguish corroded from uncorroded rebar. Our results sho.., that CT is a valid NDE technique that can be used to characterize small concrete structures. Future studies will be aimed at determining the feasibility of using CT to characterize large concrete structures in the field using a transportable CT scanner.

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UCRL-JC-104831ABST

Strain Enhanced Grain Growth in Superplastic Ultra-High Carbon Steels

C. K. Syn, D. R. Lesuer, and O. D. Sherby*

Prepared for 1991 Minerals, Metals & Materials Society Annual Meeting February 17–21, 1991.

We have been studying grain growth behaviors of superplastic ultra-high carbon steels, with 1.6 and 1.8% C, by tensile tests and metallography of the tested samples. The results indicate that the concurrent grain growth during the tensile deformation is responsible for observed strain hardening of the materials. Local grain size on tensile tested samples were measured as a function of corresponding local strain. The ratio of the net grain growth (Δd) with respect to the undeformed grain size (d_0) in the grip section was found to have an almost linear relationship to $(\varepsilon \cdot t)^{1/3}$ where ε is strain and t is time. The same relationship was also derived from the constitutive equation $\dot{\varepsilon} = Kd^{-p}\sigma^n$ where $\dot{\varepsilon}$ is strain rate, K constant, d grain size, σ stress, p and n are grain size and stress exponents, by assigning a reasonable value for p and n (2.5 and 2.0 respectively) and assuming that the measured strain hardening in the tensile tests was entirely due to the grain growth. It was further found that both the estimated and measured grain growth ratio ($\Delta d/d_0$) fall on a single line within a narrow scatter band regardless of temperature and strain rate when plotted together as a function of $(\varepsilon \cdot t)^{1/3}$. Experimental details are presented and the implications of the results and additional analysis of other materials along the same line are discussed.

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UCRL-ID-104835ABST

Three-Point Bend Creep Testing of Carbon/Epoxy

D. S. Hiromoto

This study provides data to verify theoretical models for predicting and characterizing viscoelastic behavior of fiber composites. Since performing uninterrupted creep tests for years was not feasible, creep behavior was accelerated with elevated temperatures.

An improved method was developed and implemented for measuring specimen deflection within the tight confines of an environmental chamber. This proved critical to the success of this experiment.

UCRL-CR-104838

Nondestructive Evaluation of Residual Stress in Anisotropic Materials

G. C. Johnson

The research supported under Lawrence Livermore National Laboratory Intramural Order Number 2698203, Project Title "Nondestructive Evaluation of Residual Stresses in Anisotropic Materials," focused on the ability to use a new nondestructive method for evaluating residual stresses in a wide range of materials which might exhibit anisotropy in their response. This new technique falls within the family of ultrasonic techniques referred to as acoustoelasticity.

Acoustoelasticity is an ultrasonic technique for stress evaluation which is based on the fact that the speeds at which various waves travel through a deformed body depend on the state of stress to which the body is subjected. The basic approach has been to try to obtain estimates of the stress state from sufficiently precise measurements of the velocity variations.

The work supported by this contract has conclusively demonstrated that measurements of variations in speed at which longitudinal waves travel through a stressed body are sufficient to evaluate the complete state of stress within the body, provided certain conditions are met.

The specific focus on anisotropic materials in the research was addressed in a manner which was primarily analytical. All of the experiments involving materials with substantial elastic or plastic anisotropy indicated that the materials in question exhibited a level of acoustoelastic response which was at or below the limit for useful stress evaluation. Nevertheless, the analysis performed indicates that if an experimental system is built which allows determination of the velocity variation roughly an order of magnitude more precisely than is possible with the system used in this work, the complete state of residual stress may be obtained, despite the presence of anisotropy.

The remainder of this report consists of a detailed description of the technique and experimental system proposed for the evaluation of residual stress states. The underlying analytical developments are reviewed and a numerical investigation into the application of this approach for anisotropic materials is presented. It is shown that an accurate assessment of the complete residual stress state may be obtained even in cases of extreme anisotropy. Finally, an experimental investigation of the technique is presented where the experimentally determined numerically predicted stress states are compared. It is shown that the two estimates of stress agree for the material involved.

UCRL-JC-104953ABST

Modeling the Superplastic Forming Process

E. C. Flower, D. J. Nikkel,* and D. D. Sam*

Prepared for 4th Annual IMOG Metal Forming Modeling Subgroup GE-Neutron Devices Department, Largo, Florida, October 23–25, 1990.

Superplasticity refers to the ability of a metal to undergo extensive uniform tensile plastic deformation prior to failure. Superplastic forming is a process which utilizes this material phenomena to form complex near-net shapes. Thin sheets can be formed by placing the sheet over a heated die cavity that is sealed on the periphery and an inert gas pressure applied to the top. Pressures are generally low to keep the material rate of deformation in the superplastic range which is usually between 10^{-4} to 10^{-2} per second. Critical to the process is the pressure time history and optimum die design. Critical to the economics of the process is formation at the highest rate without losing the superplastic properties. We seek to develop a method to accurately model superplastic forming of thin sheet into deep hemispherical shapes using a reverse-blow form process. Finite element (FE) modeling is used to determine the optimum die design and pressure time history. Essential to the FE analysis is the constitutive model that determines the material response. To simulate the process requires a strain rate and temperature dependent plasticity model which must also account for the complex deformation path of the reverse-blow form process. Bammann's unified creep plasticity model meets these criteria. We discuss the results of our simulations and the aspects of the material model including determining the models nine constants that are needed for temperature and rate dependent analysis.

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Modeling Superplastic Materials—Accounting for Structural Changes

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Prepared for 4th Annual IMOG Metal Forming Modeling Subgroup GE-Neutron Devices Department, Largo, Florida, October 23–25, 1990.

The forming of superplastic materials is very sensitive to the microstructure of the material and the forming parameters (primarily temperature and strain rate). We are developing a model that integrates constitutive behavior, structural change (grain growth and cavitation), and deformation stability. Such a model should be useful for the study of superplastic forming problems. The constitutive equations that we are using account

for the structure of the material through grain size and sub-grain size terms. The grain size can then change as described by the strain-enhanced grain growth laws that we are studying. Our work is largely experimental and has included the study of superplastic Ti-6A1-4V, a copper-based alloy and steel. This presentation describes our work on this model as well as the evolving microstructure during superplastic forming.

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Computer Modeling of High-Strain-Rate Testing of Sheet Material

D. H. Lassila, M. M. LeBlanc, and F. H. Magness

Prepared for 4th Annual IMOG Metal Forming Modeling Subgroup GE-Neutron Devices Department, Largo, Florida, October 23–25, 1990.

An experimental technique for high-strain-rate tensile Hopkinson bar testing of sheet material has been developed. The technique has been used to test 1.0-mm copper sheet material with different grain sizes at strain rates of 6500 per second at temperatures from 22°C to 200°C. Analysis of the tensile test was performed using a three-dimensional ALE computer code and the mechanical threshold stress (MTS) material model which has been modified to include the effect of grain size on constitutive behavior. The MTS material model with a grain size parameter is briefly described. Results of the computer modeling of the tensile Hopkinson bar test performed on different grain-size materials are discussed.

UCRL-ID-105130ABST

Geometric Effects in Tomographic Reconstruction

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In x-ray and ion-beam computerized tomography, there are a number of reconstruction effects, manifested as artifacts, that can be attributed to the geometry of the experimental setup and the object being scanned. In this work, we examine four geometric effects that are common to first- and third-generation (parallel beam, 180°) computerized tomography (CT) scanners and suggest solutions for each problem. The geometric effects focused on in this paper are: "X-pattern" artifacts (believed to be caused by several errors); edge-generated ringing artifacts (due to improper choice of the reconstruction filter and cutoff frequency); circular-ring artifacts (caused by employing uncalibrated detectors); and tuning-fork artifacts (generated by an incorrectly specified center-of-rotation). Examples of all four effects are presented. The X-pattern and edge-generated ringing artifacts are presented with actual, experimental data introducing the artifact. Given the source of the artifact, we present simulated data designed to replicate the artifact. Finally, we suggest ways to reduce or completely remove these artifacts. The circular-ring and tuning-fork artifacts are introduced with actual experimental data as well, while digital signal processing solutions are employed to remove the artifacts from the data.

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UCRL-JC-105131

NDE Environmental, Safety, and Health Activities at Lawrence Livermore National Laboratory

W. T. Fritts

Prepared for American Society for Nondestructive Evaluation Fall Conference, Seattle, Washington, October 9–11, 1990.

There has been a dramatic increase in environmental protection concerns over the last few decades. As late as 1965, there were only three federal environmental laws/regulations on the books. Today there are 26, in addition to numerous state and local legislations.

This report describes the multifaceted efforts that Lawrence Livermore National Laboratory (LLNL) is using to meet these new requirements in the area of nondestructive evaluation (NDE) activities. They include use of three major organizations at LLNL, Environmental Protection

Department, Hazards Control Department, and Health Services Department, all tasked with helping meet ES&H goals. Internal audit, training, and communication programs have been established within the Nondestructive Evaluation group to monitor and control the generation of hazardous materials. The group is also developing NDE methods to evaluate the contents of waste containers using remote sensing and analysis techniques and equipment.

UCRL-ID-105132

Computed Tomography Software and Standards

S. G. Azevedo,* H. E. Martz, M. F. Skeate, D. J. Schneberk,† and G. P. Roberson

This document establishes the software design, nomenclature, and conventions for industrial computed tomography (CT) used in the Nondestructive Evaluation Section at Lawrence Livermore National Laboratory. It is mainly a users guide to the technical use of the CT computer codes, but also presents a proposed standard for describing CT experiments and reconstructions. Each part of this document specifies different aspects of the CT software organization. A set of tables at the end describes the CT parameters of interest in our project.

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Effects of Shock Prestrain on the Dynamic Mechanical Behavior of Tantalum

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Prepared for DYMAT 91, 3rd International Conference on Mechanical and Physical Behaviour of Materials Under Dynamic Loading, Strasbourg, France, October 14–18, 1991.

An extensive number of structure/property studies on shock loading effects in metals and alloys with an FCC crystal structure have been investigated. In contrast, BCC metals with iron, molybdenum, and recently niobium have been less extensively studied. To the best of our knowledge, neither the residual microstructures or mechanical response of shock-loaded tantalum has been reported. In addition, none of the previous shock studies probing the post-shock mechanical behavior of BCC metals has investigated the dynamic reloading response, but concentrated on the post-shock quasi-static or hardness properties. To assess the dynamic mechanical response of shock prestrained tantalum, we have shock-loaded polycrystalline 99.98% Ta to 15 GPa, "soft" recovered the samples, and then sectioned the recovered discs for quasi-static and dynamic mechanical testing and TEM examination. Details of the shock recovery techniques, using an 80-mm single-stage gas gun are as previously reported.

Compression testing of both shocked and unshocked material was performed over a range of strain rates from $1.6 \times 10^{-5}\ s^{-1}$ to $5000\ s^{-1}$. At the slow strain rates, the shocked material exhibited an increase in yield strength and a decrease in work hardening rate similar to that previously documented in shock-loaded copper. However, there appears to be a major difference in subsequent work hardening of shocked Ta in comparison to Cu. Specifically, the stress strain response of the shocked and unshocked materials converge at relatively low values of true strain (20%). The strain at which convergence occurs decreases with increasing strain rate. At a strain rate of $5000\ s^{-1}$ the stress strain response of the shocked and unshocked materials is virtually identical. The strain-rate sensitivity of the flow stress at a true strain of 10% for the shocked and unshocked materials was found to be nearly identical at strain rates below $10\ s^{-1}$ and consistent with that reported. At strain rates above $10\ s^{-1}$ the shocked material exhibits a decrease in strain rate sensitivity relative to the unshocked material.

Tensile tests were performed at strain rates of $10^{-3}\ s^{-1}$ and approximated $5000\ s^{-1}$ using sheet tensile samples 1.0-mm thick. The true stress-strain response in tension was found to be similar to that in compression. However, a well defined upper yield point was observed in the unshocked material in tension. None was observed in any of the compression test results. The strain at which deformation instability occurred in the shocked material was significantly less than the unshocked material. The decrease in work hardening rate of the shocked material can account for this behavior.

Metallographic examination of the shocked Ta revealed significant amounts of deformation twins. Reloading the shocked material caused an increase in twin density. Additional metallographic and TEM observations are reported and used to interpret the deformation behavior of the shocked material.

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UCRL-JC-105244

Multiaxial Failure Characterization of Composites

S. E. Groves

At Lawrence Livermore National Laboratory (LLNL) we have been developing fibrous composite materials for use in challenging three-dimensional loading environments such as warhead penetrator cases, nuclear weapons, submarines, and munition components. One of the major difficulties inhibiting these efforts is our ability to characterize the three-dimensional performance envelope of these materials. Our most significant accomplishment has been the development of a multiaxial testing capability for composites, which has provided us with the ability to generate a significant portion of the performance envelope. The performance of fibrous composite materials is complex and highly dependent on the fiber orientation and the overall laminate configuration. The performance envelope is defined by the locus of various combinations of the three-dimensional stresses required to induce failure. Unlike metals which generally have a single failure mode, these materials possess many unique and independent failure modes which require us to generate the performance envelope or failure surface as opposed to a failure point.

The multiaxial test specimen is a 2-in.-diam composite tube with 15° cast epoxy end cones for gripping. This system is coupled into a biaxial MTS machine capable of simultaneously applying axial load, torque, and internal pressure. The primary purpose of this system is to understand the complex failure mechanisms possible for the various types of multiaxial load coupling. Through this understanding we are able to optimize our composite design. The material used for this study is T300/F263 which is a prepreg carbon epoxy material. We are currently investigating the performance of a new carbon material system known as Toray 1000 which is proving to have three times the performance of the T300 system. Visualizing the complex failure surfaces of these materials will enhance our performance modeling capabilities. The end goal of our efforts is to develop a highly capable three-dimensional failure criterion from the information gleaned in this work, which can be used to efficiently design composite structures.

UCRL-ID-105245ABST

A Guide to Using Material Model #11 in NIKE2D: An Internal Variable, Viscoplasticity Model

E. C. Flower and D. J. Nikkel, Jr.

The need to accurately model the superplastic forming process, which is highly rate and temperature dependent, motivated the evaluation of Bammann's internal variable, viscoplasticity material model. The model is based on the concepts of unified creep plasticity, but employs a yield surface for efficient implementation into large-scale numerical computer codes. It has proven to be quite successful in describing large strain, thermal-mechanical behavior of crystalline materials. Features of the model enable it to simulate the apparent strain-rate behavior exhibited by many metals above one-half the melt temperature. It is the efficient incorporation of these features that makes the model attractive for use in finite element modeling of metal deformation processes. Although this model was implemented into the Lawrence Livermore National Laboratory's NIKE2D finite element program in 1986, there have been no known reports of successful use by NIKE2D users. The purpose of this report is to provide the user the proper format to input model parameters, a procedure for determining appropriate values for material constants from experimental data, and supplemental information on the model relevant to the implementation in the NIKE2D finite element program. Detailed accounts of the theoretical aspects of the model can be found in the cited references.

UCRL-JC-105264ABST

Computerized Tomography of High Explosives and Other Applications

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Prepared for 32nd Weapons Agencies Nondestructive Testing Organization (WANTO) Meeting, Aiken, South Carolina, November 27–29, 1990.

The Nondestructive Evaluation (NDE) Section at the Lawrence Livermore National Laboratory (LLNL) has applied the advanced imaging technique of x-ray computerized tomography (CAT or CT) to provide cross-sectional views of materials, components, and assemblies for industrial nondestructive evaluation and characterization. In addition to Lab-wide utilization of our CT imaging capability, we have ongoing collaborative R&D efforts with:

- The Pantex Plant to examine the use of CT technology to inspect high-explosive pressings.
- The University of California at Berkeley to inspect concrete samples.
- The University of California at Davis to inspect soil samples.
- The Nuclear Chemistry Division, LLNL, to assay nuclear waste canisters.

An overview of our CT capabilities is presented including our Laboratory-built x-ray CT scanners and image reconstruction, display, and analysis techniques used in the NDE Section. The presentation emphasizes the industrial applications discussed above and how our CT scanners can be used as a tool for materials characterization. This presentation will reveal the usefulness of CT as an advanced tool for nondestructive inspection and characterization.

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UCRL-JC-105265ABST

Design of an Active and Passive CT Scanner to Assay Nuclear Wastes

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Prepared for Topical Conference on Industrial Computed Tomography-II, San Diego, California, May 21–23, 1991.

The current gamma-ray technique of segmented gamma scanning used throughout the Department of Energy (DOE) complex to quantify nuclear wastes in 108-L (55-gal) drums does not meet current waste acceptance criteria. This technique yields large errors for all but homogeneous waste matrices and typically employs simple nondestructive assay technology to measure the intensity of only one gamma-ray from either ^{235}U or ^{239}Pu. If the emitted, multi-energy gamma-ray spectrum can be measured in a *passive* (emission) tomographic manner, e.g., using single photon emission CT (SPECT), then the radioactive wastes can be localized to a specific volume element within the drum. Multi-energy *active* (transmission) tomographic measurements of the same drum yield an attenuation coefficient "map" of its contents. Coupling the active and passive computerized tomography data leads to spatial, content-specific attenuation coefficients, localization of the activity, and accurate quantitative assays of all detectable radioisotopes in the waste drums. This provides the isotopic-specific information required to meet the Waste Isolation Pilot Plant's (WIPP) ^{239}Pu-effective waste acceptance criterion. A similar need to accurately assay nuclear wastes using CT has been acknowledged by the Japanese and European nuclear communities.

A collaborative research and development effort between the CT Project and Safeguards Technology Program (STP) at the Lawrence Livermore National Laboratory (LLNL) has begun to improve DOE's ability to accurately assay nuclear wastes without prior knowledge of waste content. We discuss the optimum approaches necessary to couple gamma-ray isotopic nondestructive analysis (NDA) with active and passive CT nondestructive evaluation (NDE) that will result in the design of a nuclear waste-drum scanner. This active and passive CT (A&PCT) scanner will yield accurate quantitative assays of all detectable gamma-ray isotopes in 208-L waste drums. We also discuss the results obtained using a first-generation, nuclearspectroscopy-based, prototype of the A&PCT scanner. This tomographic technology can also provide accurate and complete isotopic assays of nuclear wastes for the defense and public sectors.

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UCRL-JC-105419

Computerized Calculations for Radiography and Ultrasonics

R. D. Rikard

Prepared for *Materials Evaluation*.

This paper describes a method to calculate the formulas used in nondestructive evaluation (NDE) by placing them into a spreadsheet application on a personal computer. The Microsoft Excel application on a Macintosh computer is configured to program and display the computation of various radiographic and ultrasonic parameters. Thus, the need to remember the formulas necessary to obtain the results is alleviated. After the spreadsheet is constructed, the known variables are inserted and the information desired is calculated and displayed.

UCRL-JC-105422ABST

Modeling the Influence of Structural Change on Deformation and Failure of Superplastic Materials

D. R. Lesuer, C. K. Syn, K. L. Cadwell, and S. C. Mance

Prepared for International Conference on Superplasticity in Advanced Materials, Osaka, Japan, June 3–6, 1991.

Modeling is an effective means for studying superplastic forming problems. Superplasticity is highly sensitive to microstructure. Testing/forming variables and material models for the constitutive behavior of materials during superplastic flow require accounting for microstructure, its evolution, and changes in deformation mechanism throughout the deformation history. We are developing the capability to model the superplasticity forming process. This paper describes an experimental study of the evolution of grain structure and cavitation, and the resulting influence on the stress-strain behavior and failure of two superplastic metals—a copper alloy (Coronze 638) and an ultra-high carbon steel. Our studies on grain growth during superplastic flow in Coronze 638 have expanded on the work of Caceres and Wilkinson to account for the influence of temperature and higher strain rates. We have also studied the effects of grain size distribution. Our studies have found that traditional steady-state stress-strain rate constitutive relationships (such as the Mukherjee, Bird, Dorn equation) can adequately represent the experimentally derived stress-strain behavior in Region II provided strain-enhanced grain growth and cavitation are taken into account. In and near Region III, agreement with experimental data is not as good and the constitutive relations need to be expanded to include the effects of slip creep. However, we have also examined the suitability and limitations of an instability parameter (such as defined by Caceres and Wilkinson) to predict deformation stability. For ultra-high

carbon steels, microstructural changes involve growth in the ferrite grains as well as coarsening of the carbide particles. The grain-growth kinetics in this material have been examined. An evaluation of stress-strain data has shown that, as with Coronze, the strain hardening during superplastic flow can be accounted for through strain enhanced grain growth.

UCRL-MI-105435

Modeling the Superplastic Forming Process with Two Rate-Dependent Plasticity Models in NIKE2D

E. C. Flower, D. J. Nikkel, and D. D. Sam

Prepared for 4th IMOG Metal Forming Modeling Subgroup Meeting, GE-Neutron Devices Department, Largo, Florida, December 4–6, 1990.

Presentation.

UCRL-ID-105662ABST

Joining of Polymer Composite Materials—A Survey

F. H. Magness

Under ideal conditions load bearing structures would be designed without joints, thus eliminating a source of added weight, complexity, and weakness. In reality the need for accessibility, repair, and inspectability, added to the size limitations imposed by the manufacturing process and transportation/assembly requirements mean that some minimum number of joints are required in most structures. The designer generally has two methods for joining fiber composite materials—adhesive bonding and mechanical fastening. As the use of thermoplastic materials increases, a third joining technique—welding—will become more common. It is the purpose of this document to provide a review of the available sources pertinent to the design of joints in fiber composites. The primary emphasis is given to adhesive bonding and mechanical fastening, with information coming from documentary sources as old as 1961 and as recent as 1989. A third, shorter section on composite welding is included in order to provide a relatively comprehensive treatment of the subject.

UCRL-CR-105763

Laser Ultrasonics: Current Research Needs

J. W. Wagner*

Prepared for *15,000 Final Report.*

Laser-ultrasonics refers to a range of technologies involving the use of laser electro-optical systems both to generate and to detect ultrasonic signals in and on materials and structures. Such systems have been developed to permit classical ultrasonic measurements for materials characterization, and defect identification and measurement. Unlike conventional piezoelectric ultrasonic transducers which require mechanical contact with the object being inspected, laser-ultrasonic systems are noncontacting and remote. The capability for remote measurement arises from the fact that the transduction from light energy to acoustic energy, and in turn from acoustic energy into optical information, takes place as a result of direct physical interaction between the propagating laser light (used to generate or detect ultrasound) and the surface of the test object. No intermediate transduction or couplant is required. This capability for making remote measurements is an advantage over other noncontacting ultrasonic transducers, such as capacitance transducers and electromagnetic acoustic transducers (EMATs) where relatively low frequency and short range electro-magnetic fields are employed. From the point of view of one concerned with practical applications of ultrasonic inspection and measurement methods, laser-ultrasonic systems offer the flexibility which, in principle, should permit remote ultrasonic measurements to be performed on objects at elevated temperatures or in hostile environments. Furthermore, rapid scanning of complex object shapes should be facilitated since there is no need for direct mechanical coupling. Also from the point of view of those less interested in immediate applications but concerned with fundamental aspects of ultrasonics, laser-ultrasonic systems offer great advantages. Laser-ultrasonic systems can be designed and constructed with extremely wide and flat detection bandwidth so that ultrasonic vibrational displacements can be recorded with high fidelity. In addition, there is no mechanical loading of the surface to damp, absorb, or otherwise distort the propagating acoustic energy. This feature has been used to great advantage in performing ultrasonic measurements in thin plates and films.

In spite of the great advantages offered by laser-ultrasonics, there are severe limitations which restrict its application. In fact, based on the performance of current state-of-the-art laser-ultrasonic systems, it is usually more advantageous to use conventional ultrasonic transduction methods, than it is to apply laser-ultrasonics. The main reason leading to this conclusion is the poor system detection sensitivity of laser-ultrasonic systems compared with piezoelectric transducer systems. The theoretical and practical reasons limiting laser-ultrasonic detection sensitivity are discussed.

From the discussion above, it is clear that laser-based methods for generation and detection of ultrasound are well established for laboratory use. However, for use in the field as a nondestructive testing tool or in the factory as a sensor for process control, laser ultrasonic methods suffer by comparison with more conventional contact transducer techniques. In order to overcome the limitations which restrict the application of laser ultrasonic methods, several research needs have been identified. By addressing these needs, it may be possible to broaden the range of application for laser ultrasonics.

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Applied Research Engineering Division (ARED)

This division supports LLNL physics programs in the following areas: O Division and E Division physics, Magnetic Fusion Energy (MFE) experiments, MFE development and technology, and particle-beam and free-electron laser development. These areas require support from most mechanical engineering disciplines and from specialists in normal and superconducting magnetics, cryogenic systems, vacuum systems, high-voltage components, and nucleonics.

UCRL-100531ABST, Rev. 2

A Model for the Prediction of NB3SN Critical Current as a Function of Field, Temperature, Strain, and Radiation Damage

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Prepared for 1990 Applied Superconductivity Conference, Snowmass Village, Colorado, September 24–28, 1990.

Conductors designed for fusion machines must operate at high fields, under large mechanical loads, and in a high neutron flux. Present designs favor the use of Nb_3Sn with force-cooling by supercritical helium to extract large nuclear and ac-loss heat loads. Consequently, the magnet designer must have knowledge of the critical current of the superconductor as a function of field, strain, temperature, and radiation damage. Expanding work by Hampshire *et al.* and Ekin, combined with radiation damage studies of Nb_3Sn, we express the critical field (B_{c20}) as function of temperature, strain, and damage energy (E_d). Similarly, the zero-field critical temperature (T_{c0}) is expressed as a function of strain and damage energy. The expressions for B_{c20} and T_{c0} are combined into a functional form that allows an accurate and consistent estimate of the critical current density at the operating conditions of fusion magnet conductors.

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UCRL-101185, Rev. 1

A Fuel Pellet Injector for the Microwave Tokamak Experiment (MTX)

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Prepared for *The Journal of Vacuum Science and Technology*.

Unlike other fueling systems for magnetically confined fusion plasmas, a pellet injector can deliver many fuel gas particles to the core of the plasma, enhancing plasma confinement. We installed a new pellet injector on the MTX (formerly Alcator-C) to provide a plasma with a high core density for experiments both with and without ultrahigh-power microwave heating. Its four-barrel pellet generator is the first to be designed and built at LLNL. Based on "pipe-gun" technology originated at Oak Ridge National Laboratory (ORNL), it incorporates our structural and thermal engineering innovations and a unique control system. The pellet transport, differential vacuum-pumping stages, and fast-opening propellant valves are reused parts of the Impurity Study Experiment (ISX) pellet injector built by ORNL. We tailored designs of all other systems and components to the MTX.

Our injector launches pellets of frozen hydrogen or deuterium into the MTX, either singly or in timed bursts of up to four pellets, at velocities of up to 1000 m/s. Pellet diameters range from 1.02 to 2.08 mm. A diagnostic stage measures pellet velocities and allows us to photograph the pellets in flight. We are striving to improve the injector's performance, but its operation is already consistent and reliable.

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UCRL-JC-103115

Possible Applications of Induction Linacs Driven by Magnetic Pulse Compressors

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Prepared for International Magnetic Pulse Compression Workshop, Lake Tahoe, California, February 12–14, 1990.

In the 25 years since induction accelerators were first proposed, they have been used extensively as research accelerators for investigation of a range of particle beam and radiation sources. While the technology has been applied in flash radiography, extensive use of these devices in commercial and military applications has not occurred. Over the last decade, increased understanding of the physics of beam transport and the invention of novel pulse-power designs aimed at high-repetition-rate operation have produced the technical possibility of using the technology as the power source for optical and millimeter-wave free-electron lasers (FELs), relativistic klystrons, heavy-ion accelerators, x-ray sources, CARMs, and electron beam (e-beam) waste/pollutant processors. Magnetic switching has been an important element in many of the concepts intended for the applications. We provide a brief summary of the possible applications of induction linacs driven by magnetic switchs and technical issues that must be resolved.

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UCRL-JC-103314, Rev. 1

MTX Diagnostic and Timing System for FEL Heating Experiments

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Prepared for Eighth Topical Conference on High-Temperature Plasma Diagnostics, Hyannis, Massachusetts, May 6–10, 1990.

In the MTX program, we are concentrating on experiments using intense, FEL-generated microwave pulses. In initial FEL experiments, several diagnostic instruments were operated during injection of microwave pulses with peak powers to 0.2 GW at durations of 10 ns. Fixed and spatially scanning microwave detectors and receivers and a 48-element calorimeter on the inside wall of MTX diagnosed the GW-level FEL microwave pulses to study linear wave absorption and to determine efficiencies of transmission through the quasi-optical transport system. In addition, several radially resolved measurements of plasma density, temperature, and emission were made during FEL injection and used in the analysis of microwave absorption data. A timing system, slaved to the FEL pulse arrival time, is capable of accuracy to a few nanoseconds in order to allow measurement of heating effects on the time scale of a single FEL pulse. We will discuss operation of these diagnostics and our plans for future measurements of single pulse and high average power heating experiments.

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UCRL-JC-103488ABST

AC Losses in the ITER Magnet System

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The International Thermonuclear Experimental Reactor (ITER) design study is a collaborative magnetic-fusion-energy project between the US, EC, USSR, and Japan. Since the ITER machine is designed to operate in a pulsed mode, ac losses are induced in all metallic components, including superconductors. In order to estimate the total refrigeration power required for the machine, four independent ac-loss global analyses have been performed for both poloidal and toroidal magnet systems. Preliminary results indicate that ac losses produce the dominant heat load in the PF coils and a significant fraction of the total in the TF coils. This paper reviews and compares all analyses algorithms and summarizes results.

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UCRL-JC-103489ABST

Designing for Maximum Flux Production by the Superconducting Central Solenoid of a Tokamak Poloidal-Field System

J. R. Miller

The flux swing that can be produced to induce and sustain the plasma of a tokamak is always limited by the diameter of the hole left at the center of the machine where the inboard legs of the toroidal-field coils come together. Most of the flux swing is derived from the central solenoid of the poloidal-field magnet system. Given a constrained outer radius for the central solenoid, there is an optimum inner radius that depends on conductor design choices, superconductor properties, coil-protection criteria, structural allowables, and other specific features of the coil design. This optimization process is discussed in the context of design choices for a central solenoid for ITER, the International Thermonuclear Experimental Reactor.

UCRL-JC-103490ABST

A Conceptual Design of the International Thermonuclear Experimental Reactor for the Central Solenoid

J. R. Heim and J. M. Parker

Prepared for 1990 Applied Superconductivity Conference, Snowmass Village, Colorado, September 24–28, 1990.

Conceptual design of the International Thermonuclear Experimental Reactor (ITER) superconducting magnet system is nearing completion by the ITER Design Team, and one of the Central Solenoid (CS) designs is presented. The CS part of this magnet system is a vertical stack of eight modules, approximately 16 m high, each having approximate dimensions of: 4.1-m o.d., 2.8-m i.d., 1.9-m h. The peak field at the bore is approximately 13.5 T. Cable-in-conduit conductor with Nb_3Sn composite wire is used to wind the coils. The overall coil fabrication will use the insulate-wind-react-impregnate method. Coil modules are fabricated using double-pancake coils with all splice joints located in the low-field region on the outside of the coils. All coils are structurally graded with high-strength steel reinforcement which is co-wound with the conductor. We describe details of the CS coil design and analysis.

UCRL-JC-103491ABST

A Characterization of Internal-SN Nb_3Sn Superconductors for Use in the Proof of Principles (PoP) Coil

L. T. Summers, A. R. Duenas, C. E. Karlsen,* G. M. Ozeryansky,† and E. Gregory†

High performance Ti-alloyed internal-Sn superconductors have been selected for use in the the proof of principles (PoP) coil, a 1.0-m o.d., 0.4-m i.d. solenoid designed to produce fields up to 15 T. The PoP coil, which will use forced-flow cable-in-conduit conductors (CICC), will operate at 4.2 K and moderate levels of conductor strain. Here we report the results of detailed characterizations of two proposed PoP coil Nb_3Sn 19 subelement superconducting wires of differing topology. We have investigated the critical current as a function of applied field, and applied strain. The wires were found to have excellent high field properties, providing a high performance margin for the proposed PoP coil. The field and strain dependence of J_c have been found to compare favorably with predictions from a wire performance model recently developed for Nb_3Sn superconductors.

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UCRL-JC-103596ABST

FENIX, a Test Facility for ITER and Other New Superconducting Magnets

D. S. Slack, R. E. Patrick, and J. R. Miller

Prepared for 1990 Applied Superconductivity Conference, Snowmass Village, Colorado, September 24–28, 1990.

The Fusion Engineering International Experimental (FENIX) Test Facility which is nearing

completion at Lawrence Livermore National Laboratory, is a 76-t set of superconducting magnets housed in a 4-m-diam cryostat. It represents a significant step toward meeting the testing needs for the development of superconductors appropriate for large-scale magnet applications such as the International Thermonuclear Experimental Reactor (ITER). The magnet set is configured to allow radial access to the 0.4-m-diam high-field region where maximum fields up to 14 T are provided. The facility is fitted with a thermally isolated test well, with a port to the high-field region that allows insertion and removal of test conductors without disturbing the cryogenic environment of the magnets. It is expected that the facility will be made available to magnet developers internationally, and this paper discusses general design features, construction, and capabilities.

UCRL-JC-103598ABST

Computations of Quenching and Stability in a CICC Conductor

R. L. Wong

Prepared for 1990 Applied Superconductivity Conference, Snowmass Village, Colorado, September 24–28, 1990.

The quenching and stability behavior of forced-flow helium-cooled, cable-in-conduit conductors (CICC) has been analyzed using a new computer program. This computer analysis code was developed for performing general, transient, thermal analyses on CICCs. The program includes the necessary details for the physical properties of all the constituent materials of such conductors, and accurately models the thermo- and fluid-dynamic behavior of the helium coolant starting from a wide range of initial conditions. It has been applied to a study of the stability and quench behavior of several large-scale conductor options being considered for use in the magnet systems of the International Thermonuclear Experimental Reactor (ITER) and the results are reported here.

UCRL-JC-104104ABST

A Cryogenic System for the Superconducting-Super-Collider L* Detector

D. S. Slack, J. R. Heim, C. D. Henning, J. R. Miller, and R. L. Wong

Prepared for Symposium on Detector Research and Development for the Superconducting Super Collider, Fort Worth, Texas, October 15–16, 1990.

The L* detector requires a magnet system about 26-m diam by 30-m long, generating about 0.75 T in the bore. To meet this requirement, resistive magnets would require about 25 MW on a continuous basis. Consequently, a superconducting magnet system is attractive for this application even though the field requirement is modest. This paper describes a cryogenic system to support the superconducting detector magnets. The cryogenic system proposed utilizes only components with long operating histories, and no new component development is required. Reliability is emphasized. Heat load calculations, refrigerator analysis, cooldown procedures, flow schemes, heat transfer from the conductor to the cryogen, and operating scenarios are summarized, including upset conditions in the event of a quench. The physical layout of the cryostat and refrigeration plant and required rights-of-way are also presented.

UCRL-JC-105411ABST

R&D for ITER Magnet Systems

J. R. Miller

Prepared for Twelfth International Conference on Magnet Technology, Leningrad, USSR, June 23–28, 1991.

At the beginning of the Conceptual Design Activity (CDA) for the International Thermonuclear Experimental Reactor (ITER), the four partners in the activity (the European Community, Japan, the Soviet Union, and the United States) already had active programs to support the development of superconducting magnet technology for fusion research. These programs provided the basis for selecting realistic performance goals for the ITER magnet systems. ITER magnet R&D is now in transition between the period of voluntary contributions by four individual programs and the establishment of a unified program that will support improvement of the ITER magnet designs during the Engineering Design Activity (EDA). The design activity will demonstrate the feasibility of their manufacture and reliable performance in the demanding environment of a fusion reactor. This paper briefly reviews the contributions of the individual voluntary programs and summarizes plans for the specifically focused, long-range R&D during the EDA.

UCRL-JC-105762ABST

The Effects of Thermal Precompression and Applied Mechanical Strains on High-Current Cable-in-Conduit Conductors

L. T. Summers and M. V. Ricci*

Prepared for International Cryogenic Materials Conference, Huntsville, Alabama, June 11–14, 1991.

Cable-in-conduit conductors (CICC) are preferred for large fusion magnets because of their high stability, efficient use of structural reinforcement, and ability to extract large heat loads. However, the design of magnets using CICCs requires a knowledge of cable/conduit interactions, especially the effects of thermal precompression and the transmission of electromechanical loads between the superconducting cable and the structural conduit. Here we report the critical-current performance of high-current CICCs measured as a function of externally applied static and cyclic strain at a field of 15 T. The CICCs examined have a cable-space helium fraction of about 40%, a 1-mm thick stainless-steel conduit, and a design critical current (I_c) of about 15 kA at 12 T. The mechanical properties and thermal precompression of the conductor system (cable and conduit) have been determined. The degree of strain in the superconducting filaments is estimated by comparison with Ekin's strain scaling laws and an empirical expression describing the mechanical linkage between the cable and the conduit is proposed.

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UCRL-JC-105772ABST

Design, Fabrication, and Test of a 10-W, 1.8-K Cryostat for High-Field Superconducting Magnet Geometry

D. S. Slack

Prepared for International Cryogenic Materials Conference, Huntsville, Alabama, June 11–14, 1991.

An He-II cryostat was built and tested to support the development of very-high-field superconducting magnets for NMR spectrometry. This work was funded by the National Institute of Health through Carnegie-Mellon University as part of a program of development for a 900-MHz NMR spectrometer for biomedical research, which requires the generation of >21 T by the superconducting magnet. The present cryostat served both as a test cryostat for a model coil (tested at LLNL to 20.4 T) and as a developmental model for the 900 MHz spectrometer-magnet cryostat. Because of uncertain test requirements, the present cryostat was given the capability for handling heat loads of about 10 W at 1.8 K. This paper reports details of the design, measurements of the performance over a temperature range of 1.9 to 1.5 K, details of the operating characteristics for the model-coil tests, and suggestions for improvements.

UCRL-JC-105775ABST

FENIX, a Facility for Testing High-Field/High-Current Superconductors for Fusion

J. R. Heim, M. R. Chaplin,* J. M. Parker, and D. S. Slack

Prepared for International Cryogenic Materials Conference, Huntsville, Alabama, June 11–14, 1991.

The Fusion Engineering International Experimental (FENIX) test facility has been built at Lawrence Livermore National Laboratory to test state-of-the-art superconductors for magnetic-fusion applications. Conductor test-specimen transverse-magnetic fields up to 14 T and operating currents up to 40 KA are available for standard operation. Provisions have also been made to use this facility to test pancake coils up to 10-cm thick in the future. The facility is fitted with a thermally isolated test well containing a vertical access port to the high-field region that allows insertion and removal of conductor test specimens without disturbing the cryogenic environment of the background field magnets. Conductor test specimens are set to their operational currents and fields and the specimen temperature are raised to the current-sharing temperature to get the stability temperature margin. The FENIX test facility is used to support our fusion- magnet-development program; however, our plan is to make the facility available to other magnet development programs that need high-field conductor testing. We describe design, fabrication, and operational experience of the FENIX test facility.

*Fusion Energy Sys. Div., Electronics Engineering, LLNL.

Materials Fabrication Division (MFD)

This multidisciplinary organization provides engineering development and fabrication services that are not available from commercial vendors. The number and diversity of LLNL's research efforts make this division one of the Laboratory's largest. There are approximately 400 skilled personnel and a division inventory of more than 3700 pieces of equipment.

With these facilities and the special capabilities of the staff, MFD provides research and development and fabrication services in the fields of optics, welding, vacuum processes, glass, plastics, sheet metal, metal finishing, metrology, forming, inspection, and assembly. It is responsible for conventional and numerically controlled machining of metals, high explosives, and ceramics.

UCRL-102807ABST

Diamond Turning of Optical Crystals

T. T. Saito, C. K. Syn, B. A. Fuchs, and S. P. Velsko*

We review LLNL's recent diamond turning of crystals (frequency conversion and laser hosts). Material parameters, application considerations, surface finish, and laser damage data are discussed.

*Y Division, LLNL.

UCRL-102845ABST

Lapping: Polishing and Shear Mode Grinding

N. J. Brown

Shear mode grinding appears to be a process of polishing by physical rather than chemical adhesion of particles with sizes and loads below cracking threshold.

UCRL-102849ABST

Coolant Recycling at Lawrence Livermore National Laboratory

R. H. Fasholz

Waste minimization has always been in the forefront of management concern at the Lawrence Livermore National Laboratory. During this past decade, much effort has been directed toward minimizing the Laboratory's industrial waste. Two items drive this:

- A clean environment is a better environment.
- Significant resources are associated with cleanup and disposal of hazardous wastes.

This paper will discuss one aspect of waste minimization—the recycling of spent machine tool coolant. This recycling effort is occurring within the Materials Fabrication Division at the Lawrence Livermore National Laboratory. This paper chronicles the events which moved us into the recycling business, summarizes the recycling equipment and procedures we use, analyzes the economic and payback issues, and addresses our future recycling objectives.

UCRL-ID-104094

Laser Test for Spindle Parallelism

S. L. Thompson and C. A. Chung

The purpose of this test was to check the sign convention of the straightness interferometer when it is being used to assess a spindle for parallelism to a linear axis. The sign becomes all important when removing the alignment error of the straightness reflector from the machine error.

The basic procedure is to indicate one side of the straightedge, and make a strip chart of the results. The spindle and the straightedge are then rotated 180°, but because the indicator cannot get to the reference surface of the straightedge, the indicator must be bracketed on the back side of the machine. A second trace is made of the reference surface with the polarity reversed. The

charts are then laid out with their edges parallel. A new plot is then drawn through points located midway between the existing traces, representing the machine error. The data can also be recorded for each increment again with the sign reversed on the back side. In this case, both points for each increment are added and divided by two. These points can be plotted as the machine error.

UCRL-MI-104100

Optical System Modeling Using GRIP

P. Geraghty

Prepared for Northern California Unigraphics Meeting, Tandem Computers, Cupertino, California, May 30, 1990.

Presentation.

UCRL-MI-104173

Lapping: Polishing and Shear Mode Grinding

N. J. Brown

Prepared for Optical Society of America, Science of Optical Finishing, Monterey, California, June 10–14, 1990.

Viewgraph presentation.

UCRL-MI-104174

Diamond Turning of Optical Crystals

T. T. Saito, C. K. Syn, B. A. Fuchs, and S. P. Velsko

Prepared for Optical Society of America, Science of Optical Finishing, Monterey, California, June 10–14, 1990.

Viewgraph presentation for Fabrication and Testing Workshop.

UCRL-JC-104195ABST

Design and Analysis of the Reflection Grating Arrays for the X-Ray Multi-Mirror Mission (XMM)

D. P. Atkinson, J. V. Bixler,* P. Geraghty, C. J. Hailey,† J. L. Klingmann, R. C. Montesanti, S. M. Kahn,‡ and F. B. S. Paerels‡

Prepared for SPIE, San Diego, California, July 8–13, 1990.

The reflection grating spectrometer (RGS) experiment, which has been selected for flight on the European Space Agency's X-Ray Multi-Mirror Mission (XMM), includes two arrays of reflection gratings that are placed in the x-ray optical path behind two separate grazing incidence x-ray telescopes. Each of the grating arrays picks off roughly half the x-ray light emanating from its telescope and diffracts it to a dedicated strip of charge-coupled device (CCD) detectors offset from the telescope focal plane. The arrays contain 224 gratings (100 mm × 200 mm), each mounted at a graze angle of 1.58° to the incident beam. The gratings are produced by epoxy replication of a common master onto very thin substrates. Both the gratings and the detectors are mounted on a Rowland circle which includes the telescope focus. In this paper, we review the current state of both the engineering and optical designs for the grating arrays.

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UCRL-JC-104205ABST

Dimensional Stability of Superinvar

S. R. Patterson

Prepared for SPIE, San Diego, California, July 8–13, 1990.

The unloaded dimensional stability and thermal expansivity of a single furnace melt of superinvar have been measured at room temperature using interferometric techniques

Thermal expansivity has been determined with an uncertainty of several parts in $10^8/°C$, while dimensional stability has been determined with an uncertainty of order one part in 10^9/day. Samples subjected to plastic deformation in their processing history displayed a stability improvement from 20.5×10^{-6}/day to 5.5×10^{-9}/day and a reduction in thermal expansivity from $0.56 \times 10^{-6}/°C$ to $0.23 \times 10^{-6}/°C$ associated with the increased mechanical work in the material.

UCRL-JC-104362ABST

The Measurement and Finite Element Analysis of the Dynamic Stiffness of Nonuniform Clearance, Gas, Thrust Bearings

J. W. Roblee, P. Holster,* and J. Jacobs*

Prepared for ASME-STLE Tribology Conference, Toronto, Canada, October 7–10, 1990.

This paper presents an overview of a finite-element-method (FEM) approach for the calculation of the dynamic stiffness of circular, externally-pressurized, gas thrust bearings with a nonuniform clearance. Some observations are made about the characteristic behavior of gas bearings subject to dynamic loading. The primary emphasis of this paper, however, is the development and qualification of a test apparatus and the necessary test techniques for measuring dynamic stiffnesses up to 250 N/μm at frequencies up to 2000 Hz. A complete experimental verification of the FEM model is presented in a later paper.

*Philips Research Laboratories, Eindhoven, The Netherlands.

UCRL-JC-105129ABST

A Novel Image Rotator

C. H. Gillespie

Prepared for SPIE, Optical Engineering, Northern California Regional Technical Meeting, November 15, 1990.

This three mirror image rotator is unique because it offsets the optical axis allowing another freedom to align a system. However, the compound entrance and exit mirror angles make the out-of-plane reflection complex to analyze. A rotation of the out-of-plane mirror around the optical axis does not produce the expected 2x rotation in the image. Perspective views were developed using a Unigraphic computer drawing program. Then by tracing a pattern reflected through the system, a relationship between the mirror rotation and image rotation was graphed. A least-squares-fit polynomial was next fit to the data to interpolate and design the mirror coordinates for our desired image rotation.

A large aperture stereo viewing system uses two of these rotators. The system records several stereo pairs of images on film while a remote event is changing at high speed. The optics consist of sets of relay and field lenses centered on parallel optical axes. The axes are then brought together at the film plane with the proper image rotation and viewing angles. To do this, three large 35-cm mirrors and their mounts were designed, positioned and aligned in each line of sight to preserve a 1/4 wave F#/40 quality at 20-cm aperture.

The mirror mounts were placed in a spherical seat with its center of rotation at the mirror face. By analyzing and designing coordinates for the mirrors, alignment was simplified to pointing the optic centerline from the center of one mirror onto the center of the next. The specification of mirror flatness and optical path length is also considered.

UCRL-JC-105133ABST

Lapping: Fracture and Shear Mode Grinding

N. J. Brown

Prepared for Asia-Pacific Conference on Optical Technology, Marina Mandarine Hotel, Singapore, October 22–27, 1990.

It is increasingly important to understand the mechanisms of fracture in abrasive wear in order to control the depth of the fractured layer and at times reduce or avoid it completely. The driving force here is the requirement to add precision grinding to the deterministic repertoire of the ultra-precision machinist, and the need to

bring the increased versatility and productivity of ultra-precision machining to the optical fabrication process.

We have been studying both three-body and two-body abrasive processes. This paper considers three-body processes primarily but some comparisons to two-body processes are made where applicable. This paper covers the threshold separating the region-of-shear mode from fracture mode. We cite our own work, and that of Soviet and Japanese grinding researchers as well as the indentation studies of Lawn *et al.* and Hagan to show that for glasses such as BK7 and fused silica the transition is found with abrasives sizes well below 5 μm. After establishing this limit, this paper examines fracture parameters.

UCRL-MI-106024

Tool-Setting and Tool Characterization at LLNL

D. C. Thompson

Prepared for JOWOG 39 Manufacturing Technology SUBWOG B Machine Tools and Equipment—Atomic Weapons Establishment, Bldg. F6.1, Aldermaston, Reading RG 7 4PR, England.

Presentation.

UCRL-MI-106025

Certification of Process (COP) Gauge Control and Data Acquisition System

D. C. Thompson

Prepared for JOWOG 39 Manufacturing Technology SUBWOG B Machine Tools and *Equipment—Atomic Weapons Establishment*, Bldg. F6.1, Aldermaston, Reading RG 7 4PR, England.

Presentation.

ME Administration

This section contains abstracts of documents authored under the aegis of the overall ME Deparment.

UCRL-MI-104579

Totally Contained High Explosive Test Facility Site 300

C. F. Baker

Prepared for Twenty-Fourth DOD Explosives
Safety Seminar, St. Louis, Missouri,
August 28–30, 1990.

Presentation.

Work Done Under Contract

UCRL-CR-103853ABST

The Safety Approach of the Modular High-Temperature Gas-Cooled Reactor (MHTGR)

F. A. Silady* and L. L. Parme*

The modular high-temperature gas-cooled reactor (MHTGR) is an advanced reactor concept under development in a cooperative program involving the U.S. government, the nuclear industry, and the utilities. The design utilizes the basic high-temperature gas-cooled reactor (HTGR) features of ceramic fuel, helium coolant, and a graphite moderator. However, the specific size and configuration of the MHTGR are selected to utilize the inherent characteristics of these materials to develop passive safety features that provide a significantly higher margin of safety than current generation reactors. The design meets the U.S. Environmental Protection Agency's Protective Action Guidelines at the site boundary, hence precluding the need for sheltering or evacuation of the public during any licensing basis event. This safe behavior is not dependent on operator action, is insensitive to operator error, and does not require a leak-tight containment building.

A safety summary is provided of the response to events challenging the functions relied on to retain radionuclides within the coated fuel particles. The regulatory interaction process and results are discussed through reviews of the Nuclear Regulatory Commission (NRC) staff, NRC contractors, and the Advisory Committee for Reactor Safeguards (ACRS). Insights from the NRC's Draft Safety Evaluation Report are discussed.

*General Atomics.

ASNT Spring Conference

This section is devoted to abstracts presented at the ASNT Spring Conference, Oakland, California, March 18–22, 1991.

UCRL-JC-104111ABST

Continuum X-Ray Gauging of Multiple-Element Materials

D. L. Lewis, M. R. Gabel, and C. M. Logan

Also presented at the CUBE Symposium, Santa Fe, New Mexico, November 27–30, 1990.

A system has been developed for element quantification of materials with known constituents. It utilizes an x-ray tube to generate a photon spectrum from which the photon transmission of the material is measured at selected energies. The abundance of each element is then iteratively extracted using characteristic attenuation coefficients and the material bulk density and thickness.

UCRL-JC-105138ABST

X-Ray Tomographic Microscopy (XTM)

J. R. Celeste, J. D. Kinney, and G. J. Devine

This XTM technique is a tool which is used to nondestructively image materials microstructure. High resolution (15 micron) three-dimensional images are obtained via tomographic reconstruction of projection data. A microfocus x-ray source is used to generate x-rays. X-ray images of a sample material are generated on a cadmium tungstate scintillator in a vacuum (10^{-3} Torr) chamber. A liquid cooled CCD camera is focused on the scintillator using a diffraction-limited optics train that optimizes the magnification/demagnification for individual samples. Positioning stages in the vacuum chamber are used to center and rotate the sample in the camera's field of view. One-hundred-eighty angular views are usually taken to reconstruct the three-dimensional images.

UCRL-JC-105226ABST

Quantitative Radiography

C. M. Logan, J. M. Hernandez,* and G. J. Devine

Film radiography can be refined to yield information far beyond detection of flaws. In order to quantitatively interpret film radiographs, it is necessary to digitize the images. In addition, all steps of the radiographic process must be carefully characterized and controlled. We have developed an integrated system of quantitative radiography that displays accurate, high-resolution pseudo-color images in units of areal density of the subject part. In order to achieve this accuracy, we control exposure conditions, flight path, film handling, and processing. X-ray attenuation standards must be included every few centimeters within each film. Corrections for source uniformity and scattering are required. We create areal density images that agree with monochromatic x-ray gauging and with destructive chemical analysis to within a few percent.

*Nuclear Energy Systems Division, Electronics Engineering Division, LLNL.

UCRL-JC-105228ABST

Misuse of Radiographic Images for Interface Characterization

C. M. Logan, D. W. Dobie, and G. J. Devine

Gaps or bonding agents at interfaces usually have different x-ray attenuation properties than the surrounding materials. This property makes it possible to form a transmission x-ray image of the interface region. This image is frequently used to infer something about the width of the interface region. Correct interpretation of these images is difficult or even impossible for most radiographic setups. Our analysis shows that the actual interface width is significantly less than a direct measurement of the film image would suggest for most common situations. The "width" of the image recorded on film depends more on radiographic setup than on interface width.

UCRL-JC-105229ABST

A Collimator for Depth Profiling by XRF

B. J. Schumacher, M. R. Gabel, and K. W. Dolan

We have fabricated and characterized a tungsten-loaded epoxy collimator for spatially-resolved x-ray florescence in composite materials with low x-ray attenuation. This collimator resolves a voxel of approximately a 1-mm cube. It incorporates many converging holes to attain reasonable count rates. This report discusses the design, fabrication, and characterization of this collimator.

UCRL-JC-105230ABST

Inspection of Inhomogeneities in Low Density Silica Aerogel Using Optical Interferometry and Proton Energy Loss Tomography

B. J. Schumacher and L. W. Hrubesh*

Silica aerogel is highly porous, optically transparent glass with pore and particle sizes less than the wavelength of visible light. We have examined inhomogeneities in low density aerogel which may have been caused by convection currents during the formation of the aerogel. We used optical interferometry to determine the refractive properties and proton energy loss tomography to image the density in three dimensions.

*Chemical Sciences Division, Chemistry & Materials Science Department, LLNL.

UCRL-JC-105231ABST

Low Energy Radiographic Sensitivity for Density Changes in Polymer Materials

K. W. Dolan and J. E. Kervin

Radiographic sensitivity results are presented for low-kilovolt exposures relating film density gradients to physical density differences in thin polymer materials. Special low-kilovolt radiography techniques are described which include preparation of polymer and kapton step wedges, use of helium beam path, thin polymer film cassettes, fine grain film, and Be x-ray tube window. Results of low-kilovolt x-ray tube spectral measurements, including effects of air attenuation and filters, spectral impact on sensitivity, and equivalency relationships between polymer and kapton step wedges are presented and compared with calculations. Density sensitivities >1% to 3% were obtained for thin polymer materials with thicknesses ranging from 10- to 120-mg/cm^2.

UCRL-JC-105232ABST

Point Spread Function Estimation and Correction for Digitized Radiographic Images

J. J. Haskins, D. J. Schneberk,* and M. King*

The advent of the Du Pont digitizer has made possible the quantitative processing and analysis of radiographic images. This digitizing process means, however, that the blur in radiographic images (due to geometric unsharpness, scatter, etc.) is now convolved with the blur introduced by the digitizer. In an effort to better characterize film digitizing as an imaging system, we have applied three techniques for calculating point spread function blur in digitized radiographic images:

- An ASTM approach.
- An approach currently used in medical scanners (Siebert & Boone).
- A procedure developed here at LLNL.

The three techniques are compared on their underlying assumptions, ease of application, and performance. In each case, the estimated point spread functions (PSF) are deconvolved from digitized images, using standard Weiner filtering techniques.

*Application Sys. Div., Computation Directorate, LLNL.

UCRL-JC-105233ABST

Quantitative Nondestructive Environmental Characterization of Advanced Materials

D. W. Dobie, J. R. Celeste, and G. W. Krauter*

Polymethylpentene, polystyrene, agar, carbon, and aerogel, are advanced materials that have unique engineering properties. In an effort to understand material response to temperature and humidity changes, nondestructive quantitative characterization was performed. Computer controlled environmental test chambers were designed and built to cycle the material through temperature and humidity excursions while observing mass and dimensional changes. Material expansion and water absorption coefficients were quantified. Polymethylpentene and polystyrene materials have coefficients of thermal expansion (CTE) of 100 and 40 µm/m°C, respectively. The CTE of aerogel and carbon is approximately 5 µm/m°C. Agar is unique with a negative CTE. Water absorption causes expansion in agar that results in a coefficient of 500 µm/m%RH. These materials can absorb up to 13% of their original mass with a 40% relative humidity change. Most respond linearly to temperature and humidity excursions while others respond nonlinearly and have hysteresis. Humidity control has proven to be extremely important when evaluating advanced materials.

*Nuclear Energy Sys. Div., Electronics Engineering, LLNL.

UCRL-JC-105239ABST

Calculation of X-Ray Tube Spectra on the Macintosh

D. E. Perkins

It is often useful to calculate the spectral and intensity effects of filters, tube window thickness, flight path composition, and other beam hardening elements. In order to make these calculations available to more users, we have modified and enhanced a section of the NBS code (NBSGSC) called CALCO that computes x-ray spectra. The code computes the spectra of an x-ray tube given the current, voltage, and an anode material. The code will also calculate the effects of a Be window, a filter of any element chosen, and the flight path composition. The code has been adapted to run on a Mac II. The output is available in photons per second or rads per hour.

UCRL-JC-105238ABST

X-Ray Film Processor Monitoring and Control for Increased Reproducibility

P. B. Mohr, E. O. Updike, and J. M. Fugina

Variability in the quality and consistency of precision densitometric x-ray film images processed in automatic processors has been substantially reduced by exercising active monitoring and control of the physical variables and background chemistry in which the image formation (developing) and fixing take place. The novelty of the chosen system features on-line measurement and computer monitoring of pH and bromine ion concentration (by x-ray fluorescence) along with nine other process variables. In addition to increased uniformity of the film product, the regimen has resulted in decreased maintenance and materials costs. A description of the computer-directed monitoring system is presented together with supporting data. A study of the major factors affecting quantitative image reproducibility and alternate means for processing is underway with a major film and processor manufacturer. The initial results are summarized.

UCRL-JC-105248ABST

Closure Weld NDE of High-Level Radioactive Waste Containers

R. A. Day

The final seal weld in high-level radioactive waste containers is particularly important to their integrity because it must be done remotely and because the available thermo-physical processes that could be used to improve the weld properties are limited by the waste forms. Nondestructive evaluation (NDE) of the final seal weld is accordingly very important. Ultrasonic methods are favored because the high background radiation levels limit the use of radiographic methods. Ultrasonic methods possess the ability to detect small flaws in welds of candidate alloys. An experimental system has been constructed that allows easy software construction, changes in configuration, and multiple transducer manipulation at moderate cost. The system is accurate and uses object-oriented programming to allow "point and click" style programming. Experience to date shows that programming cost is reduced by about five-to-eight times with a slight loss in data acquisition speed over traditional "C" programming.

Data obtained with the system are being used to evaluate the inspectability of candidate alloys joined by candidate weld methods. The alloys under consideration include austenitic AISI 304L, AISI 316L, alloy 825, as well as copper alloys CDA 102, CDA 613, and CDA 715. Joining methods include fusion welding, electron beam welding, and inertial welding. All alloys are known to have anisotropic and inhomogeneous acoustic properties when fusion welded. Flaws as small as 1% of the wall thickness are currently of interest, although acceptance criteria for the closure joint are not yet established.

CUBE Symposium

This section is devoted to abstracts presented at the CUBE Symposium, Santa Fe, New Mexico, November 27–30, 1990. CUBE stands for "Computer Use By Engineers."

UCRL-MI-103777

Acoustic Ray-Trajectory Code

S-W Kang and J. L. Levatin

Viewgraph presentation on the development of an acoustic ray propagation code that accounts for changing meteorological conditions in the downrange direction.

UCRL-MI-103778

Computation of Viscous Acoustic Flow Fields with Compliant Boundaries

C. S. Landram and R. M. Trusty

Viewgraph presentation on the motivation and system analysis, theory, numerical scheme, results and experiment comparison, and the conclusions drawn.

UCRL-MI-103779

Computational Scheme for Examining and Optimizing Microchannel Cooling

C. S. Landram

Viewgraph presentation on the purpose and problem description, its formulation, the solution strategy using a hybrid computational model, and the results.

UCRL-MI-103820

Application of the Finite Element Technique in Modeling Superplastic Metal Fabrication Operations

D. D. Sam,* E. C. Flower,† and D. J. Nikkel†

Viewgraph presentation.

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UCRL-MI-103823

AUTOCASK—*AUTO*matic Generation of Three-Dimensional Storage or Transportation *CASK* Models

S. C. Sommer and M. A. Gerhard

Viewgraph presentation.

UCRL-MI-103824

Make Computer Analysis a Snap with Special Purpose Drivers

M. A. Gerhard

Viewgraph presentation on use of special purpose drivers to automate compile and link programs, modification of geometries, setup analysis inputs, run analyses, post process analysis results, and backup files and results.

UCRL-JC-103832ABST

DYNA3D SEPW Design Analysis for Moderate to Severe Impacts

R. W. Logan

This work presents the results of numerical analysis of LLNL's earth-penetrator designs for the recently concluded Strategic Earth Penetrator Weapon (SEPW) Phase II study. Many separate issues are addressed, such as the G-loads experienced on impact, and the effects of rock type, velocity, angle-of-incidence (AOI), angle-of-attack (AOA), and comparisons of field observations with DYNA3D and SAMPLL simulations. Other issues include weight tradeoffs for the four different warhead designs considered in this study, and the tradeoff between graphite/epoxy and steel penetrator cases. The best designs require a short length, sufficient taper, and a stiff warhead package. Steel cases appeared best for severe impacts, based on our limited experience and conservative design approach with the composites. The composite cases do appear to save weight in moderate impacts.

UCRL-JC-103833ABST

DYNA3D Example Problems Review

S. C. Lovejoy

DYNA3D is a widely used explicit nonlinear finite element code for the dynamic response of solids and structures. An example problems manual has been written that describes in detail the solution of nine sample problems using DYNA3D. The example problems include both solid and shell element types. For each example problem, there is first an engineering description of the physical problem to be studied. Next, the analytical techniques incorporated in the model are discussed, including salient features of DYNA3D used in the model. INGRID commands required to generate the mesh are listed, and sample plots from the DYNA3D analysis are given. Finally, there is a description of the TAURUS post-processing commands used to generate the plots of the solution. The manual provides a set of sample problems to use in verifying the installation of DYNA3D on a particular computer.

UCRL-JC-103834ABST

Structural Analysis of the X-Ray Collimator in Bunker 801, Site 300, Lawrence Livermore National Laboratory

S. C. Lovejoy

High powered x-ray cameras are frequently used for diagnostics of detonating explosives. Such a device exists in Bunker 801 at Site 300, the explosives testing grounds for Lawrence Livermore National Laboratory. The existing collimator on the x-ray camera contains a substantial quantity of depleted ^{238}U. The components made of this material must be periodically removed for maintenance subjecting technicians to low-level doses of radiation. A new design for the collimator replaces the D-238 with tungsten to reduce or eliminate exposure.

A concern exists about the structural integrity of the new design when subjected to a blast load. The new design is qualitatively investigated for load paths and suspect weak components. Both two- and three-dimensional finite element analysis are used to predict the structural responses of the weak components in the new design. A total of seven variations of the new design are evaluated. A best design is selected and presented in detail.

UCRL-JC-103836ABST

CAD/CAM Software and Its Use with Nonlinear FEM Analysis

T. E. Spelce

Recently, the Nuclear Explosives Engineering Division of the Mechanical Engineering Department at Lawrence Livermore National Laboratory undertook a comprehensive study of the commercial software available for use in CAD/CAM applications. In conjunction with this study, the engineering-analysis related capabilities of these packages were evaluated based on a small test suite of problems indicative of routine analysis tasks.

This talk briefly summarizes the engineering analysis capabilities of the commercial packages surveyed. In addition, some remarks concerning extending these packages to make them compatible with current in-house FEM analysis tools are provided.

UCRL-JC-103837ABST

DYNA2D Enhancements and Improvements

T. E. Spelce

Several new features have been added to the production version of DYNA2D at Lawrence Livermore National Laboratory. These developments include a material model driver, stress initialization, arbitrary Lagrangian-Eulerian capabilities, automatic contact, and element erosion. These features have been contributed by other investigators in one form or another and are now fully integrated into one version available for Cray, UNIX, and VAX/VMS platforms. In addition to providing examples of applications, modeling and run-time considerations are discussed.

UCRL-JC-103838ABST

Clad Wire Drawing

P. J. Raboin

Clad wire drawing is analyzed using the finite element program NIKE2D. The purpose of this work is to study the wire drawing process and to assist in the design and manufacturing of clad wires. Design factors such as core-to-clad diameter ratio, die design, wire materials, and lubricants are varied, and analyzed with a finite element simulation of the wire drawing process. From this work, instabilities which result in prediction of wire "sausaging" (uneven deformation in the core and clad material) are observed in the finite element calculations. This phenomenon is observed experimentally. Finite element analyses indicate that decreasing the ratio of clad wire flow strength to core wire flow strength will reduce the sausaging effect. Other results from this work include predictions of residual stresses, effective plastic strains, and redundant strains.

A creep analysis, using a rate-dependent material law developed for NIKE2D, was performed on a clad wire supporting a fixed weight. Force versus time predictions from this analysis indicate how much tension clad wires can hold and when a clad wire may break. This information is necessary for straightening curled wire, further wire drawing, and final assembly.

UCRL-JC-103839ABST

Finite Element Simulation of HERF Metal Forming

P. J. Raboin

Finite element calculations with NIKE2D have simulated HERF metal forming. The purpose of this work is to develop predictive capabilities for finding the room temperature strength of materials forged at high temperatures using high-energy-rate forging methods. So far, three goals have been achieved in this work. A strain hardening, plastic strain-rate-dependent material law has been added to NIKE2D. Finite element simulations of HERF forward extrusions of 21-6-9 stainless steel have been performed for 6-in.-diam billets reduced to 5 and 4 in. Twelve 6-in.-diam pieces of 21-6-9 stainless steel were HERF-forward extruded to final diameters of 5, 4, and 3 in. The deformation predictions made by NIKE2D were made prior to the work being performed and are compared to the actual results. This ongoing work has led to the development of a temperature- and plastic-strain rate dependent material law, material strength tests of specimens machined from the HERF'd billets and correlations between the predicted and measured room temperature strength of 21-6-9 stainless steel.

UCRL-JC-103840ABST

Structural Response of Reinforced Concrete Viaducts to Ground Motion Using 3-D Finite Element Continuum Analysis

G. J. Kay

Three-dimensional continuum models of two freeway sections which were damaged in the October 16, 1989, Loma Prieta earthquake were generated and studied for structural responses under base excitation loading conditions. This study was part of an LLNL initiative which was undertaken to provide assistance to Caltrans engineers in their efforts to retrofit the California highway system for protection from anticipated earthquakes.

The continuum models which were used in the analysis simulated the reinforced concrete bents, roadways, structural joints, and retrofit jacketing in the two freeway sections between expansion joints. Each model contained three bents and two levels of roadway. The mesh generation code INGRID was used to generate the models and the finite element code NIKE3D was used to perform the analysis. Actual joint dimensions were employed in the analysis and constant ground accelerations were applied directly to the base of the structure. Constitutive models were employed in the analysis which allowed for tensile- and compressive-type concrete failure. Limitations in modeling resolution and stability precluded taking the NIKE3D calculations out to simulated freeway collapse loads but load levels were determined which represented reasonable limits for structural integrity. Limit loads were determined both with and without retrofit assemblies in place.

UCRL-JC-103841ABST

Finite Element Failure Analysis of 21-6-9 HERF Forgings

R. W. Logan

This work addresses actual HERFing of a 21-6-9 dimpled-hemi forging, and the numerical simulation of the failures and successes encountered. The first experimental attempt at making the forging was a failure, resulting in cracks in the detailed pole region. The second attempt used a radically different and more complicated forging approach, which was successful. Early attempts to model the problem with NIKE2D failed to determine why the first method failed and the second succeeded.

In this work, a tractable method for simulating HERFing with DYNA2D was developed, followed by the development of a history, direction, and pressure-dependent forming-limit failure model for bulk forming. The method is simply an extension of the circle-grid based forming limit diagram (FLD) procedure used in sheet forming. The model internally tracks conditions leading to failure of an element, after which the properties of that element are degraded and the simulation may continue. This feature is significant since it allows the potential for tracking progressive failures. Stability and convergence issues are discussed.

Use of the FLD-pressure (FLD-P) method in DYNA2D resulted in immediate agreement with the actual forming operations of HERF input energy, and failure and success of the two forming methods. Sensitivity studies showed that the method is not overly sensitive to uncertainties in material properties. The tentative conclusion is that since the failure limits are so sensitive to prior material condition and pressure during forming, a model that captures these effects even reasonably well will have predictive capability. This analysis has led to a further investigation of the properties of 21-6-9 stainless both during and after forging, and to the incorporation of a strain, rate, and temperature dependent model into the FEM codes.

UCRL-JC-103842ABST

CADD Produced Shaded Pictures Using Attributes

O. Alford

CADD-produced shaded pictures lend themselves quite readily to the most fundamental purpose of the graphic language, namely, communication of ideas. Shaded pictures clear up any ambiguities that are reflected in a three-dimensional wire frame model; consequently, from the initial stage of design (concepts and proposals) to the final stage of design (marketing) we have relied heavily on the use of shaded pictures to convey ideas. A further refinement of shaded graphics is the capability to include attributes that enhance the appearance of the pictures. An attribute is a quality or property that belongs to a solid or surface. It can be considered as an integral part of the solid or surface that will be shaded and provide an expanded definition of the solid or surface. Also, for the sake of this discussion, we will think of an attribute as an external characteristic that impinges on the model to be shaded that will effect the overall composition of the final graphic (i.e., multiple light sources). Attributes such as reflective surfaces, textures, shadows, and multiple light sources promote realism to shaded pictures. This discussion deals exclusively with shaded pictures that incorporate attributes.

UCRL-JC-103843ABST

A Toroidal-Shaped Charge for Cutting Large Diameter Holes in Thick Steel Targets

R. W. Rosinsky

We have been investigating annular charges that cut large-diameter holes in thick, steel plates. Specifically, our task has been to produce the largest diameter hole that we can in a 2- to 4-in.-thick steel plate from a maximum 6 in. diam, 10 lb charge. Our approach to the problem has been to search the literature for candidate designs, the candidate designs analytically using

our two-dimensional Lagrangian and Eulerian hydrodynamics codes, and then test the most promising design using high-energy (21 MeV) flash x-rays and steel plate targets.

Our search of the literature produced two generic candidate designs, a platter charge and an annular shaped charge with a wedge cross section. Analytically, the best platter charge we could design within the given limitations produced a 4-in.-diam hole in a 2-1/2-in.-thick steel plate. The best annular shaped charge with a wedge cross section also produced a 4-in.-diam hole but could not perforate a 2-in.-thick steel plate. Based on our previous work with hemispherical shaped charges, we originated a third candidate design, a toroidal-shaped charge (i.e., an annular shaped charge with an arc cross section). Analytically, we showed that a plane wave initiated, toroidal-shaped charge produced a cylindrical jet with twice the kinetic energy of a comparable annular-shaped charge with a wedge cross section. With the extra energy, we could also produce a radially expanding jet to get a larger-diameter hole and still get increased penetration.

Our presentation includes the toroidal-shaped charge design, the analysis of it, the flash x-rays from the tests, and pictures of the post-test targets.

UCRL-JC-104087ABST

PALM2D: A New Coupled Thermomechanical Code

B. E. Engelmann

PALM2D is a new nonlinear finite element program for the coupled thermomechanical response of solids in two dimensions. The code has been developed at LLNL by Bruce E. Engelmann, Robert G. Whirley, and Arthur B. Shapiro, and is based on the highly successful codes TOPAZ2D and NIKE2D. The thermal problem may include temperature dependent thermal conductivities and convection boundary conditions, and the mechanical problem may include large deformations and strains as well as material nonlinearities such as plasticity. Coupling is achieved through a staggered step formulation. Highlights of the code design and its capabilities are presented. In addition, recent developments such as thermal contact resulting from mechanical contact/impact along slideline interfaces are discussed.

UCRL-JC-104088ABST

Recent Developments in DYNA3D at LLNL

R. G. Whirley

DYNA3D is an explicit, nonlinear, finite element code developed at LLNL for the analysis *of solids and structures. DYNA3D* has seen wide application to problems ranging from automotive crashworthiness to EPW impact simulation. This presentation will give an overview of recent enhancements to DYNA3D at LLNL, and will focus on the development of a fully vectorized two-invariant cap model implementation. This new constitutive law permits more accurate DYNA3D modeling of the stress-strain behavior of concrete and soil materials under complex loading histories. Other recent developments are briefly summarized and a number of example problems are discussed.

UCRL-JC-104089ABST

Recent Developments for NIKE3D

B. N. Maker

Over the last two years several important features have been added to NIKE3D, LLNL's three-dimensional implicit finite deformation FEA code. These include two new material models for anisotropic thermoelastic analysis of solids and laminated shells, enhanced eigenvalue extraction capability, an incompatible modes element, the YASE shell element, a stress initialization feature for coordinated analysis with DYNA3D, improved user interaction, and support for versions running on UNIX workstations. These and other recent developments are described.

UCRL-JC-104153ABST

3-D Visualization Techniques for Finite Difference and Finite Element Modeling

M. Christon and A. Dawood*

The current class of supercomputers enables complex physical processes (which had previously been considered numerically intractable) to be simulated with relative ease. However, the immense volumes of data produced by large scale finite element and finite difference models have created the need for robust workstation applications which allow interactive graphical interrogation of such data. This has been facilitated by increased desktop computing power, improved bandwidth of local- and wide-area networks, and the widespread acceptance of graphical user interfaces. Readily available workstation applications (netware) are used to illustrate volume, surface, and section visualization techniques for three-dimensional data from two large-scale simulations. The first problem considered is three-dimensional natural convection in a porous medium simulated with a multi-grid finite difference model. Temperature and stream function data are probed by viewing multiple orthogonal slices through the physical domain and volume renderings of the data. The graphical data manipulation is performed locally on a workstation using the X window system and a client application, or with the computing power of a remote supercomputer employing the X client-server model. The second simulation is a deforming finite element model of coupled heat conduction and mass diffusion with phase transformation. Section views are used to explore three-dimensional temperature and mass concentration fields, while surface renderings are employed to illustrate temperature distributions at the phase transformation interface. The visualization techniques serve to demonstrate the mechanism of graphical interrogation of data from large scale simulations using readily available applications and mid-range workstations. The ultimate goal for such tools is to reduce the time for assimilation of numerical results allowing detailed investigations of complex physical phenomena.

*Colorado State University, Fort Collins, Colorado.

UCRL-MI-104159

3-D Visualization Techniques for Finite Differences and Finite Element Modeling

M. Christon and A. Dawood*

Viewgraph presentation on three-dimensional visualization requirements, three-dimensional multigrid FD model of natural convection in a porous medium, and three-dimensional deforming FE model of coupled heat conduction—mass diffusion.

*Colorado State University, Fort Collins, Colorado.

UCRL-JC-104452ABST

Damage Initiation in Precision Grinding of Glass

D. J. Nikkel, Jr.* and K. L. Blaedel†

Traditional methods of fabricating high precision aspheric optics involve grinding to an approximate shape followed by a costly labor intensive cycle of polishing and measuring to obtain the final part. While grinding is a more accurate fabrication process, traditional grinding techniques leave the surface of the glass with an unacceptable level of damage, in the form of relatively deep cracks, which requires the subsequent polishing process to remove the damage. However, experimental results indicate that there is a regime of grinding, involving very low loads and depths of cut, in which material is removed in a ductile manner rather than by the propagation of cracks. This is referred to as ductile- or shear-mode grinding.

In order to develop a robust grinding process which will operate in the ductile regime and design appropriate machinery, it is necessary to understand what governs the transition between brittle and ductile grinding. Actual grinding of glass is a very complex physical process. It involves the mechanical interaction between the grinding grit and the glass, temperature effects, and chemical effects from the high moisture sensitivity of the glass. This study focuses on the mechanical interaction between the grinding grit and the glass, and in particular examines the effect of grit geometry on determining whether material will be removed in a ductile or brittle manner.

Finite element analysis is used to study the indentation of BK-7 glass by three different indenter geometries, ranging from blunt to sharp. A criterion for the initiation of cracking as proposed by Griffith is based on macroscopic stresses in a material used to examine what effect grit geometry has on initiation of deep cracks. Based on these indentation calculations for small grits (where the depth of indentation is a significant fraction of the indenter size) there is a clear difference between the results for the three different indenter geometries. However, the difference is not great enough to expect grit geometry to play the critical role in determining the transition between brittle and ductile behavior during material removal.

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UCRL-JC-104855ABST

Casting Process Modeling

A. B. Shapiro

Objectives: Our goal for FY91 is to develop a two-dimensional planar and axisymmetric simulation tool for casting manufacturing processes. We want to use this modeling tool to predict the final shape and stress state of a cast part. This will require a coupling of thermal, mechanical, and chemical effects. We plan to develop the required numerical algorithms to achieve this and will collaborate with the NWC plants (e.g., Y-12) and industry (e.g., GE Aircraft Engines) for process specification and experimental measurements for validation of the software. Research next year will extend work to three dimensions.

Background: The Laboratory enhanced safety program, casting manufacturing by the NWC production plants, and the DOE initiative in waste minimization all have an immediate requirement for casting process modeling. Individual heat transfer codes (e.g., TOPAZ2D), solid mechanics codes (e.g., NIKE2D), and chemical codes do exist. However, a coupled thermal-mechanical-chemical code with the required modeling features to predict the final shape and stress state of a cast part does not exist.

Scope of Work: Algorithms are researched and developed to:

- Model latent heat release on solidification phase change.
- Model material mechanical behavior near the solidification temperature and volume change on solidification.
- Model the part-mold interface allowing motion and gaps, and their effect on the thermal contact resistance.
- Model surface chemical oxidation which requires an additional manufacturing process to remove.

These algorithms are implemented in the TOPAZ2D + NIKE2D coupled code PALM2D. PALM2D is validated by simulating simple casting experiments on site and full manufacturing processes in collaboration with NWC plants and industry. Possible approaches to simulating fluid flow and microstructure evolution are investigated.

UCRL-MI-105429

Recent Developments in DYNA3D

R. G. Whirley

Viewgraph presentation covering YASE shell element, NIKE3D to DYNA3D stress initialization, interactive material model driver, cap model, and other developments.

UCRL-MI-105430

CAD/CAM/CAE Applied to Nonlinear FEM

T. E. Spelce

Viewgraph presentation on the design/engineering cycle.

UCRL-MI-105431

Recent Developments for NIKE3D

B. N. Maker

Viewgraph presentation covering the history and characteristics of NIKE3D, nonlinear and linear equation solving, new element formulations, new material models, new boundary conditions, etc.

UCRL-MI-105660

Finite Element Failure Analysis of 21-6-9 Stainless HERF Forgings

R. W. Logan

Viewgraph presentation including a problem, solution, and example of the predictive capability for metal forming analysis.

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