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METALS AND CERAMICS DIVISION PROGRESS REPORT FOR PERIOD ENDING DECEMBER 31, 1992

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Date Published: April 1993

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6285
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

Reports previously issued in this series are as follows:

ORNL-28	Period Ending March 1, 1948
ORNL-69	Period Ending May 31, 1948
ORNL-407	Period Ending July 31, 1949
ORNL-511	Period Ending October 31, 1949
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ORNL-754	Period Ending April 30, 1950
ORNL-827	Period Ending July 31, 1950
ORNL-910	Period Ending October 31, 1950
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ORNL-1875	Period Ending October 10, 1954
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Credits:
Composition and makeup: G. R. Carter
Editing: K. Spence

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OVERVIEW

This report provides a brief overview of the activities and accomplishments of the Metals and Ceramics (M&C) Division during the period October 1991 through December 1992. The division is organized to provide technical support, primarily in the area of high-temperature materials, for the various technologies being developed by the U.S. Department of Energy (DOE). Activities span the range from basic research (through applied research and engineering development) to industrial interactions (through cooperative research and a strong technology transfer program). The division is organized in functional groups that encompass nearly all of the disciplines needed to develop and to apply materials in high-temperature applications. Sections 1 through 5 describe the different functional groups; Sect. 6 provides an alternative view of the division in terms of the major programs, most of which cross group lines; and Sect. 7 summarizes external interactions including cooperative research and development programs, educational activities, and technology transfer functions. Appendices describe the organizational structure, note personnel changes, present honors and awards received by division members, and contain listings of publications completed and presentations made at technical meetings.

Several organizational changes were made during the reporting period. Jim Stiegler, who served as the Metals and Ceramics Division Director from 1984-1992, became an Associate Director of ORNL responsible for Nuclear Technologies. Douglas Craig assumed the responsibilities of Division Director in June of 1991. Ron Beatty was named the leader of the Ceramic Science and Technology Section, and Arvid Pasto replaced Ron as the Ceramic Processing Group Leader. Tom Zacharia was appointed Materials and Process Modeling Coordinator to accomodate the growth in the division's modeling activities. Bruce Cox assumed responsibility for the Ceramic Specimen Preparation User Center and Tom Morris for the newly established Ceramic Manufacturability Center, both of which are part of the High Temperature Materials Section.

The collection of work supporting the different energy technologies in the division strengthens our overall research effort. Development of a new material is a lengthy and expensive undertaking that is often beyond the capabilities of any individual program. Cooperation between programs is enabling us to pursue alloy development activities more vigorously than would be possible otherwise. For example, the Basic Energy Sciences, Fossil Energy Materials, and Advanced Industrial Concepts Materials programs and the Martin Marietta Energy Systems, Inc., Technology Applications Program are all contributing to the development of iron-aluminide alloys. This collaboration has increased the scope of our program and has accelerated the development of these materials. Cooperative Research and Development Agreements have allowed us to strengthen our ties to industry and the relevancy of our research and development (R&D) to the problems of many industrial segments.

Several members of the division received major awards. Stan David was named a Corporate Fellow in recognition of his continuing accomplishments in the fields of welding science and technology. Stan also received the Comfort A. Adams Lecture Award. Eal Lee, Monty Lewis, and Lou Mansur received an R&D 100 Award for "Hard-Surfaced Polymers." Man Yoo was notified that he would be awarded an Alexander von Humbolt Research Fellowship. Seven division staff members were also named fellows of major societies. Everett Bloom and Martin Grossbeck were named fellows of the American Nuclear Society; Fahmy Haggag, Randy Nanstad, Dick Heestand, and Man Yoo were named fellows of ASM International; and Stan David was named a fellow of the American Association for the Advancement of Science.

A report of this type can do little to capture the excitement of research in the division. It is, at best, an index of activities in our various groups. Contact authors of the various sections for more information on our work or, better still, plan on a visit to discuss it in more detail.

1. ENGINEERING MATERIALS

G. M. Slaughter and H. W. Hayden

This section is responsible for determining and evaluating the suitability of engineering materials for use in various energy systems; for developing and commercializing new engineering alloys; and for determining and developing improved fabrication, joining, and nondestructive testing (NDT) techniques to ensure the structural integrity of materials and components in specific applications. It comprises approximately 70 staff members, about half of whom are professionals. Research and development (R&D) activities are carried out in six different laboratories, which bear the functional names Corrosion Science and Technology, Fracture Mechanics, Materials Joining, Mechanical Properties, Materials Processing, and NDT. Additionally, division support for the Heavy-Section Steel Irradiation (HSSI) Program and the High Flux Isotope Reactor (HFIR) Surveillance Program is administered through this section. A materials and process modeling coordination function was initiated this year in the section. Brief descriptions of work performed and major accomplishments of these groups and program functions are presented.

1.1 HEAVY-SECTION STEEL IRRADIATION PROGRAM—*W. R. Corwin*

Maintaining the integrity of the reactor pressure vessel (RPV) in a light-water-cooled nuclear power plant is crucial in preventing and controlling severe accidents and the potential for major contamination releases. The RPV is one of only two major safety-related components of the plant for which a duplicate or redundant backup system does not exist. It is imperative to understand and predict the capabilities and limitations of its integrity. In particular, it is vital to fully understand the degree of irradiation-induced degradation of the RPV's fracture resistance which occurs during service, since without that radiation damage, it is virtually impossible to postulate a realistic scenario that would result in RPV failure.

For this reason, the HSSI Program has been established by the U.S. Nuclear Regulatory Commission (USNRC) in the M&C Division at ORNL to provide a thorough, quantitative assessment of the effects of neutron irradiation on the material behavior and, in particular, the fracture-toughness properties of typical pressure vessel steels as they relate to light-water-reactor (LWR) pressure-vessel integrity. Effects of specimen size, material chemistry, product form and microstructure, irradiation fluence, flux, temperature and spectrum, and postirradiation annealing and reembrittlement are being examined on a wide range of fracture properties including fracture toughness (K_{Ic} and J_{Ic}), crack-arrest toughness (K_{Ia}), ductile-tearing resistance (dJ/da), Charpy V-notch (CVN) impact energy, dropweight nil-ductility temperature, and tensile properties. Models based on observations of radiation-induced microstructural changes using the atom probe field ion microscope (APFIM) and high-resolution transmission electron microscope (HRTEM) provide improved bases for extrapolating the measured changes in fracture properties to wider ranges of irradiation conditions. The principal materials examined within the HSSI Program are high-copper welds since their postirradiation properties are most frequently limiting in the continued safe operation of commercial RPVs.

Of particular interest are the efforts during the past year concerning the examination of irradiation effects on the fracture and crack-arrest toughness in the low upper-shelf (LUS) weld from the Midland Reactor. A new irradiation facility was installed at the University of Michigan Ford Reactor and irradiation of the Midland weld begun. The facility was needed to replace a similar one, now out of service, at the shut down Oak Ridge Research Reactor (ORR), to permit the irradiation of capsules containing the large fracture-mechanics specimens (up to 45 kg each) utilized in HSSI programmatic research. Collaborative efforts with a DOE-funded program were also initiated to perform the extensive dosimetry experiments and neutron source-term and transport calculations needed to fully characterize the neutron exposure conditions within the reactor.

Experimental and analytical studies to understand the effects of irradiation exposure parameters were intensified with the completion and publication of a rate-theory-based embrittlement model. Significant improvements in understanding effects of irradiation temperature and flux provided fundamental reasons for the observed differences in embrittlement in test versus power reactor irradiations as well as the potential for a method to reconcile their results. It was also shown that the overall contribution to the total embrittlement from matrix-type defects (dislocation loops, vacancy clusters, etc.) is about the same as that from impurity-rich (Cu, P, etc.) precipitates and clusters. Detailed calculations and dosimetry measurements of exposure conditions in the HFIR revealed wide variations in flux and spectrum at the surveillance specimen positions but did not allow the resolution of the previously observed accelerated embrittlement. Unexplainable inconsistencies among the individual dosimeters likely hold a key to the problem and have led to a substantially increased NRC-funded effort at ORNL to perform additional dosimetry within the HFIR. Other new experimental efforts to aid in understanding effects of exposure conditions were also begun, including the collaborative study with DOE-funded programs to examine low-temperature irradiation embrittlement in numerous model alloys and pressure-vessel steels for fluxes varying over several orders of magnitude, as well as the insertion of research specimens into the surveillance capsules at the Diablo Canyon Reactor, to directly assess embrittlement in test versus power reactors.

International collaboration significantly increased during the year. Information exchange with the Russians on LWR embrittlement expanded to include interlaboratory testing of a common specimen set to ascertain the degree of correspondence between U.S. and Russian fracture testing techniques as well as joint irradiation of exchanged RPV materials by both sides. Arrangements were also made to host a visiting scientist from the Kurchatov Institute in Moscow at ORNL for one year. Detailed negotiations were conducted with the Japan Atomic Energy Research Institute (JAERI), and a collaborative research agreement was drafted for the HSSI Program to participate in the examination of the RPV from the decommissioned Japanese Power Demonstration Reactor. The metallurgical, fracture, and dosimetry studies being conducted on this material will provide an enhanced knowledge of embrittlement during actual service and further underpin the overall understanding of irradiation-rate effects on embrittlement.

A major new programmatic initiative was begun last year on the behavior of RPV steels following toughness recovery during annealing and subsequent embrittlement during reirradiation. The focus of this task is to establish the relationship between the changes in fracture toughness of the material needed for engineering evaluations of the vessel and the changes in Charpy impact properties that comprise the vast majority of existing data on annealing and reirradiation. This research is providing an improved basis for predicting and regulating the amount of residual toughness that will remain during the continued operation of a pressure vessel after thermal annealing, since annealing is the only practical means for reducing existing embrittlement in an operating pressure vessel. A comprehensive data base of materials annealing data was assembled and used to evaluate existing models of annealing recovery. Preparations were made to anneal and reirradiate previously irradiated inventory remaining from earlier HSSI irradiation series, including the initiation of design of a capsule capable of encapsulating and reirradiating "hot" specimens. Lastly, specimens were incorporated into the large capsule containing LUS weld samples being irradiated at the University of Michigan that will allow the initial assessment of fracture toughness versus Charpy impact properties to be made.

Results from the HSSI studies will be integrated to aid in resolving major regulatory issues facing the USNRC that involve RPV irradiation embrittlement such as pressurized-thermal shock, operating pressure-temperature limits, low-temperature overpressurization, and the specialized problems associated with LUS welds. Taken together, the results of these studies also provide guidance and bases for evaluating both the aging behavior and the potential for plant-life extension of LWR pressure vessels.

1.2 CORROSION SCIENCE AND TECHNOLOGY — *J. R. DiStefano*

The Corrosion Science and Technology Group continued work on tasks involving both metallic and ceramic materials in aqueous, gaseous, and liquid-metal environments. R&D tasks have supported Conservation, Fossil, Fusion, New Production Reactor (NPR), and Space Nuclear Power (SNP) programs as well as the Advanced Neutron Source (ANS) Project.

We have continued to utilize the ANS Corrosion Test Loop to investigate the corrosion characteristics of aluminum alloys under the extreme heat-transfer conditions associated with fuel cladding in experimental and production nuclear reactors. This year, we conducted a series of five long-term tests on 8001 Al relevant to the proposed NPR-heavy-water reactor (HWR). In these tests, each one up to eight weeks in duration, the measured film growth rates were shown to be sensitive to both thermal-hydraulic and chemical system variables and were compared with the predictions of existing data correlations. In addition, the results were examined in the context of our earlier experiments on 6061 Al over a different range of test conditions.

The Fort Saint Vrain (FSV) steam generator offers a unique opportunity to gather information for the NPR-Modular High-Temperature Gas-Cooled Reactor (MHTGR). Seven of twelve ringheaders at FSV cracked adjacent to welded nozzles. We initiated a failure analysis program to assess the extent of secondary-side corrosion and the metallurgical and microstructural state of the materials due to fabrication and service. Optical metallography from failed regions of the ringheader revealed a large-grained microstructure, probably the result of "warm-working" during fabrication. Chemical analyses of the materials of construction have shown that there is a failure correlation with a particular heat of material. Future work will center on characterizing the secondary-side corrosion damage, if any, and the relationship between microstructure, chemistry, and mechanical properties to determine the cause of the failures.

In cooperation with CAPCIS March Ltd., electrochemical noise (EN) technology is being investigated as a corrosion surveillance method for corrosion testing. EN gives instantaneous information regarding both uniform and localized corrosion processes and does not require the use of a reference electrode. EN will initially be applied in the model boiler tests to be performed for the NPR-MHTGR in cooperation with ABB-Combustion Engineering in Chattanooga, Tennessee.

Tasks on the high-temperature corrosion of advanced aluminides and intermetallics were conducted for the Fossil Energy Program as part of overall alloy development initiatives. Recent ORNL results had shown significant improvement in the room-temperature ductility of iron aluminides when aluminum concentrations are reduced to the 16 at. % level. Therefore, we initiated a study to define the critical concentration of this element for resistance in high-temperature oxidizing and oxidizing/sulfidizing environments. These have been determined to be 18 and 20 at. % Al for H_2S-H_2O-H_2 and air environments, respectively. Adding 5% chromium to the 16 at. % Al alloys significantly improved the equivalent of Fe_3Al (28 at. % Al) in terms of air-oxidation resistance. We also initiated a cyclic oxidation experiment with iron aluminides containing 16 to 28 at. % Al and found beneficial effect of small additions of zirconium on scale adherence for Fe_3Al alloys. Iron aluminides with 16 at. % Al and additions of chromium (5%) and zirconium (0.1%) were superior in scaling resistance to binary alloys of 16 and 20 at. % Al and exhibited weight changes comparable to the Zr-containing Fe_3Al alloys.

A related task in support of the Fossil Energy Program entailed the development of phase stability diagrams for silicon carbide in the presence of sodium contaminants as contained in typical coal gasifier and pressurized fluidized-bed combustion environments. These results have provided guidance to the development of SiC as a high-temperature filter material for these environments.

In support of the development of high-strength Cr-Cr_2Nb alloys, the kinetics, scale composition, and spallation tendencies of Cr-6 and -12 at. % Nb alloys were characterized for high-temperature air exposures. Multilayer scales with a pure chromia outer layer were formed, and the alloy with the higher niobium content performed significantly better in terms of lower overall weight gain and resistance to spallation. This behavior was ascribed to an increased volume fraction of the Cr_2Nb-Cr eutectic mixture at the expense of the Cr-rich phase.

As part of the overall effort to better understand the characteristics of protective oxide scales on advanced alloys, depth-sensing submicron indentation testing was used to measure the elastic-plastic behavior of sintered chromia and oxide scales formed on pure chromium in air. Within experimental uncertainty, the mechanical properties of the scales and those of the corresponding bulk oxide were generally comparable. Such findings have important implications in predicting scale failure criteria for high-temperature alloys.

Vanadium and vanadium alloys are attractive low-activation materials (LAMs) for the first wall/blanket (FWB) structure of a fusion reactor. However, the chemical reactivity of vanadium-base alloys could result in unacceptable oxidation or embrittlement by oxygen, carbon, nitrogen, or hydrogen. Therefore, the effect of simulated fusion reactor-helium environments on room-temperature mechanical properties and fracture surface morphology of vanadium-chromium-titanium alloys was investigated between 500 to 700°C. Exposures for 1008 h in He+70 vppm-H (measured oxygen partial pressures of 10^{-12} atm) resulted in complete embrittlement of all the alloys in room-temperature tensile tests. The fracture mode was primarily cleavage, probably caused by a hydrogen-induced shift in the ductile-to-brittle transition temperature (DBTT). These results suggest that oxidation alone may not be the limiting consideration in terms of loss of structural integrity. Changes in temperature to near room temperature during startup, shutdown, and maintenance could result in catastrophic failure of the structure if hydrogen is present in the helium.

In FY 1992, there was a significant increase in corrosion-related tasks for the Conservation Program. A study of high-temperature environmental effects on SiC-reinforced SiC composites was started as part of the Continuous Fiber-Reinforced Ceramic Composites Supporting Technologies task. Thermogravimetric analysis was used to study the reaction kinetics associated with high-temperature air oxidation of graphite- or BN-coated Nicalon™-reinforced SiC composites. For those with graphite interlayers, the shapes of the thermogravimetric curves, and the dependencies of weight changes on interfacial layer thickness and exposure temperature, could be explained on the basis of concurrent reactions associated with oxidation of the graphite and the formation of SiO_2 on the matrix and fibers. Preliminary correlations between oxidation kinetics and fracture properties were made.

In cooperation with the Ceramic Processing Group, studies of the environmental compatibility of ceramic heat exchanger materials have continued. We evaluated the reaction of ceramic/ceramic composites exposed in an industrial hazardous waste incinerator and determined the degradation in mechanical strength of SiC/SiC composites resulting from elevated-temperature air exposure. The degradation of ceramic materials exposed to steam-methane reformer environments was characterized, and a system to conduct further studies in simulated reformer environments was constructed.

In support of the development of heat pump systems that offer opportunities for significant energy savings, we studied the interactions between container materials and $LiBr_2/LiNO_3$/4% NH_3-H_2O working media. The working fluid with a 3:1 ratio of $LiBr_2/LiNO_3$ exhibited the lowest corrosivity, and types 304L and 316L stainless steel displayed good corrosion resistance to that fluid.

A staff member of the group has a principal role in performing an assessment of materials R&D needs related to advanced fuel cells and batteries for transportation applications. The intent is to define the areas where materials development could make significant contributions to the improvement of electrochemical propulsion systems. We expect that, as follow-on to the assessment, the Conservation Program will establish a national program that addresses the materials needs identified by industry. The R&D efforts will be conducted by industry, national laboratories, and universities.

To support the development of advanced gas turbine systems with improved efficiencies and duty cycles, we completed a state-of-the-art review of high-temperature alloy systems currently used in gas turbine systems together with the projected technology advancements that should derive from ongoing research. We also completed an assessment of corrosion problems and research opportunities within the paper and pulp industries in the United States as part of a Department of Energy (DOE) initiative to transfer materials technology to these industries.

Nb-1Zr% is a candidate structural material for compact lithium-cooled reactor systems being designed for space applications. Because mechanical properties and corrosion resistance can be significantly affected by oxygen (components must be protected from oxidation during ground testing), we have now measured the oxidation rates of Nb-1Zr%

at temperatures from 773 to 1350 K and at oxygen partial pressures of 10^{-5} to 10^{-7} Pa for times up to ~2000 h to provide quantitative guidelines for system design and operation. The effects of concomitant oxidation/corrosion behavior were also determined including conditions under which effects of oxygen can be mitigated by the formation of ZrO_2.

Staff members have also provided support to various organizations within MMES in the form of consulting, failure analysis, and materials recommendations. Problems addressed included storage of radioactive or hazardous sludge/salvaged items from the Kerr Hollow quarry pond. Recommendations for tank materials used in long-term storage of radioactive waste at the Melton Valley storage facility were provided. Structural materials used in the MMES/Toxic Substances Control Act waste incinerator were evaluated, and the failure of a cooling water pipe servicing the HFIR was analyzed. We are also continuing to assist the K-25 site in investigating the failures of four carbon steel cylinders used for the long-term storage of depleted UF_6. Two of the failures were traced to external corrosion and the other two to mechanical damage during the cylinder stacking process.

1.3 FRACTURE MECHANICS — *R. K. Nanstad*

The Fracture Mechanics Group investigates the fracture resistance of structural materials, particularly steels for pressure vessel applications. This requires expertise in experimental fracture mechanics and metallurgy. Programs are sponsored by both the USNRC and the U.S. DOE. We are currently emphasizing the materials property needs for the MHTGR under the NPR Program, Heavy-Section Steel Technology and Irradiation (HSST and HSSI, respectively) Programs, ANS, Magnetic Fusion Energy (MFE), Fossil Energy Materials, and Advanced Industrial Concepts (AIC) Materials Programs.

For the MHTGR-NPR Program, irradiation effects studies for the steel RPV and projects to investigate the high-temperature fracture mechanics properties of structural materials for the steam generator and reactor internals were continued. Charpy impact specimens of reactor vessel steel irradiated at 60°C were tested and compared with results from specimens previously irradiated at higher temperatures. The results confirmed previously determined correlations between irradiation-induced changes in yield strength and Charpy transition temperature, as well as demonstrating the slight sensitivity to decreasing irradiation temperature from 200 to 60°C, for the material and neutron exposure conditions examined. A specification for irradiation of specially designed capsules incorporating tailoring of the neutron spectrum was developed, and preliminary calculations demonstrated the feasibility of such experiments in the University of Michigan's Ford Reactor. For the high-temperature fracture mechanics studies, test methods development continued along with completion of procurement and initial assembly of additional equipment such as high-temperature environmental chambers and electronic controls for the two servohydraulic machines.

For the HSST Program, the task regarding margin assessments during startup and shutdown operations in commercial LWRs continued. The results of the studies will be used by the USNRC to decide whether to relax the current requirements upon which pressure-temperature limits are based. The task involves identification and characterization of the fracture toughness of potential local brittle zones in weldments of reactor vessels, analysis of the significance of cleavage pop-ins, and a comparison of fracture toughness from standard fatigue-precracks and arrested cracks. The project involves cooperative research with Battelle Columbus Laboratories and the University of Maryland. Variations in yield strength and flow properties in local brittle zones [heat-affected zones (HAZs)] in weldments of reactor vessels were measured using automated ball indentation tests. For our continuing investigation of the role of specimen size effects in elastic-plastic fracture mechanics, experiments were conducted to provide additional data for statistical analyses and for analyses of the limitations of small-scale yielding criteria in cleavage fracture toughness measurements. An off-site, three-month collaborative assignment at GKSS in Germany and collaboration with researchers at VTT in Finland resulted in information sufficient for final development of a draft standard test method for transition region fracture toughness testing of pressure vessel steels under the jurisdiction of the American Society for Testing and Materials (ASTM). The draft standard has been presented to the appropriate ASTM E24 subcommittee for review. A detailed analysis of fracture toughness results from specimens which exhibited cleavage pop-ins concluded that, unless a pop-in is clearly proved to be statistically unrelated to the overall fracture toughness data population, the fracture toughness determined from that pop-in should be considered significant to design safety analysis. The experiments at the University of Maryland resulted in the conclusion that initiation fracture toughness values from arrested cleavage cracks were nominally the same as those from fatigue precracked specimens. Characterization studies were conducted to compare fracture toughness results from deeply cracked compact specimens with those from both shallow and deeply cracked three-point bend specimens. The experiments showed generally good agreement between the deeply cracked specimens while the shallow cracked specimens exhibited, as expected, higher toughness at a given temperature. Detailed fractographic studies were conducted to determine the cleavage origin location relative to the final precleavage crack tip as well as the length of the blunting zone. These measurements will be used to compare various methods of determining the crack-tip opening displacement and for determination of the maximum stress location as part of a project to investigate the effects of biaxial constraint on fracture behavior.

For the HSSI Program, studies continued on the Fifth, Sixth, and Tenth Series. The Fifth and Sixth Series examine the upward temperature shifts and shapes of the American Society of Mechanical Engineers (ASME) Code K_{Ic} and K_{Ia} curves using two high-copper welds. Statistical analyses of the K_{Jc} results show that the irradiation-induced shifts of the mean fracture toughness curves and curves fit to bound the data are greater than those of the Charpy impact energy curves and that the slopes of the mean curves have decreased somewhat; the lower boundary curve for the highest copper weld exhibits a significant decrease in the slope. This means that current procedures, which assume that fracture toughness changes are the same as Charpy impact changes, are nonconservative. A final report on this project was published. For the Sixth Series on irradiated crack-arrest toughness, testing of duplex crack-arrest specimens was completed, and preliminary analyses of the results indicate good comparison between the irradiation-induced crack-arrest temperature shifts and the Charpy impact shifts. The Tenth Series involves irradiation of the LUS weld material removed from the Midland Unit 1 reactor vessel that was installed but never operated. The weld metal from that reactor vessel is identical to that identified as the controlling material (for pressurized thermal shock analyses) in at least five operating nuclear reactors. For one characterization study, a report was written that documented the wide variation in transition temperature, as well as a very wide variation in copper content and different distributions of copper content in the beltline and nozzle course welds, that will require us to consider the welds as two different materials within the irradiation studies. Baseline fracture toughness testing for both the beltline and nozzle course welds has been completed, and a comprehensive report is in preparation. The design of large capsules for irradiations in the Ford Reactor at the University of Michigan was completed, and irradiation of the first capsule is under way. A new task has been initiated regarding the use of thermal annealing to recover radiation embrittlement, and the design of experiments is under way. Considerable evaluations were conducted for the USNRC regarding irradiation embrittlement and fracture toughness of the Yankee Nuclear Power Station reactor pressure vessel.

Fracture toughness tests were continued with advanced nickel aluminides for the AIC Materials Program and with advanced iron aluminides for the Fossil Energy Materials Program (FEMP). For a cast Ni_3Al alloy, relatively good fracture toughness in a ductile-tearing mode was exhibited from room temperature to 600°C while tests at 650°C revealed a substantial reduction in fracture toughness and a change in fracture mode to interdendritic fracture. At 650°C, the yield strengths of both the wrought and cast materials remained high. Efforts on the Fe_3Al alloy system have focused on reduced-aluminum alloys with aluminum content as low as ~8%. Such a decrease in the aluminum content results in substantial reduction of the transition temperature (from ~300 to 150°C) and increase in the upper-shelf energy but also produces an alloy that does not have an ordered structure. Investigations with other variations of alloy content are continuing. These testing programs have demonstrated the necessity of evaluating the fracture toughness properties of all the materials proposed for structural applications.

For the ANS Program, mechanical property and fracture toughness tests were conducted with the 6061-T651 aluminum plate procured for the irradiation effects project and showed relatively low fracture toughness of the aluminum alloy in the unirradiated condition. Testing of the first group of specimens irradiated to 1×10^{22} neutrons/cm^2 (thermal) in the HFIR was completed and revealed only a slight irradiation-induced increase of the yield strength and a slight decrease of the fracture toughness. Irradiation of the next capsule to a higher neutron fluence (1×10^{23} neutrons/cm^2) is under way in the HFIR. The results from the irradiation experiments will be used to make judgments regarding replacement schedules for the core pressure boundary tube in the reactor.

For the MFE Program, Charpy impact testing of subsize specimens of LAMs continued with variants of unirradiated 3Cr alloys containing alloying additions of such elements as tungsten, vanadium, carbon, molybdenum, tantalum, titanium, and boron. The alloys are also given normalization heat treatments with variations in tempering temperatures and times. For the International Thermonuclear Experimental Reactor (ITER) Program, studies were performed that involved the development of fracture toughness testing techniques with miniature disk-shaped compact specimens (about 5 mm thick and 12 mm in diameter) and testing of irradiated disk-shaped specimens. The materials currently under evaluation include several variants of type 316L stainless steel. Tests of unirradiated specimens have shown that these miniature, disk-shaped compact specimens can be tested under remote conditions in a hot cell. Testing of irradiated specimens has begun with successful tests having been conducted from room temperature to 200° C.

1.4 MATERIALS JOINING — *S. A. David*

The Materials Joining Group continues to conduct R&D for the Basic Energy Sciences (BES), Fossil Energy, AIC Materials, SNP, Fusion Energy, Office of Naval Research (ONR), and NPR Programs. Also, several Cooperative Research and Development Agreements (CRADAs) have been established jointly with industries. In addition, the group provides a wide variety of joining-related services to the Oak Ridge Y-12 Plant and to other divisions at ORNL.

At the request of DOE, ORNL coordinates the activities of the national BES Welding Science Programs in the United States. This includes publication of an annual newsletter.

The in-house BES Fundamental Welding Science Program investigates the physical metallurgy of weldments and develops the capability to predict weld-metal microstructure and properties. The program consists of four major parts relating to the study of (1) mathematical modeling, and its verification, of welding processes; (2) solidification behavior of weld metal; (3) correlation of thermal history and phase stability of weldment microstructure; and (4) activities related to coordination of BES welding programs and ORNL-industry cooperative programs.

Existing mathematical models of transport phenomena are being applied to investigate microstructural development and are also being extended to include other realistic welding processes such as multipass welding with filler-metal additions. Solidification studies emphasize an understanding of the development of fusion zone (FZ) microstructures from a fundamental viewpoint. These studies include the application of single crystals and rapid solidification techniques. Phase stability studies concentrate on the stability of HAZ microstructures and the response of the FZ microstructure to elevated-temperature exposure. A range of welding processes is utilized, including high-power beam techniques. The microstructural character and behavior of welds are evaluated using optical microscopy, analytical electron microscopy (AEM), indentation mechanical properties testing, instrumented Charpy impact testing, and thermomechanical simulation.

We are continuing to use single-crystal welds in order to increase our understanding of the factors that influence the development of FZ microstructures. Electron beam (EB) welding and extensive metallographic characterization were used to study the formation and selection processes in dendritic microstructures that occur during the welding of two differently oriented Fe-15Ni-15Cr single-crystal pieces. In general, the bicrystal weld microstructure is a simple composite of microstructures expected in each of the two single-crystal halves. A computational model was used to predict the surface temperature distribution of the gas tungsten arc (GTA) weld pools in 1.5-mm-thick type 304 stainless steel. The welding parameters for the calculations were chosen to correspond to an earlier experimental study that produced high-resolution surface temperature maps. One of the motivations of the present study was to verify the predictive capability of the computational model. Comparison of the numerical predictions and experimental observations indicates excellent agreement, thereby verifying the model.

Interrupted creep tests were performed at 650°C on types 308 and 308 controlled residual elements (CRE) material in both the homogenized and as-welded conditions to examine the effect of stress on the aging behavior of these steels. The microstructures were evaluated in order to determine the mechanism by which CRE additions, and specifically titanium additions, improve the elevated-temperature creep properties of type 308 stainless steel. The Ti-modified type 308 stainless steel exhibits a considerably lower steady-state creep rate, which results in a longer rupture life. In addition, the modified material has a more uniform distribution of precipitates than the unmodified alloy. The continuous network of carbides found in the unmodified type 308 steel, along grain boundaries (GBs) [homogenized material] or at the ferrite/austenite interfaces (weld material), is avoided. This continuous carbide network in the type 308 steel provides sites for the nucleation of extensive intergranular cracks during tertiary creep.

For the Radioisotope Thermoelectric Generator (RTG) Space Program, test procedures have been established to assess the relative weldability of iridium alloys on a batch-to-batch basis. To date, over 30 production batches have been evaluated, showing a wide range of hot-cracking sensitivity as measured by the sigmajig test. Recycled iridium alloy has been shown to have a higher sensitivity to hot-cracking than virgin material for reasons that are not yet fully explained. The sigmajig test is also being used to characterize developmental iridium alloys.

The MFE Program has involved development of welding procedures and parameters and weldment properties evaluations for the ITER, with emphasis on thick-section welds. The electroslag welding process is being used to join stainless steel up to 8 in. (200 mm) thick in a single pass. Mechanical properties tests include yield strength, tensile strength, toughness, and fatigue crack growth rate at room temperature and 77 K.

The AIC Materials Program emphasizes development of weldable FeAl-type alloys, both for use as monolithic structural materials and as weld overlay cladding on stainless or low-alloy steel substrates. Resistance to hot-cracking in these alloys was found to be higher, dependent upon alloy composition (particularly boron, carbon, and niobium). Excellent weldability was achieved with some compositions, and cold-cracking could be avoided for all compositions by the use of preheat and postweld heat treatment. Efforts are under way to develop a shielded metal arc (SMA) electrode formulation to deposit some of the desired alloy compositions.

The FEMP has been concerned with improving the weldability of Fe_3Al-type alloys. A wide range of hot-cracking sensitivity was determined using the sigmajig test. Additional alloy compositions are being evaluated with the goal of optimizing both mechanical properties (primary creep strength) and weldability. As with the higher aluminum content alloys, preheat and postweld heat treatment are necessary to avoid cold-cracking.

A Defense Programs (DP) CRADA has been prepared with the Oak Ridge Y-12 Plant and Edison Welding Institute to characterize and standardize weldability test techniques. The proposed program would involve redesign of the sigmajig test system, fabrication of a new unit, and participation in a round-robin test program to evaluate and standardize several weldability test techniques.

Ceramic brazing studies continue to be supported by the Ceramic Technology Project (CTP), and the emphasis of this activity during FY 1992 was on high-temperature brazing of silicon nitride. Joints of Ti-vapor-coated Si_3N_4 were made by vacuum brazing at 1130°C and used to provide specimens for flexure testing at room temperature. The results indicated that annealing at temperatures up to 700°C for times up to 100 h does not adversely affect joint strength. Testing at 800°C resulted in a large decrease of joint strength, and the cause of this behavior was investigated metallographically. Microchemical analysis showed that some decomposition of the Si_3N_4 occurred during brazing. However, no unusual enrichment of Si was found in the reaction layers near the brazed surfaces, and the exact cause of the strength decrease at 800°C was not determined. Further analysis of this behavior was planned. Also, the package developed by GTE Laboratories, Inc., on a subcontract we monitored for analyzing the stress state of ceramic-to-metal joints and their behavior under applied loads was transferred to computers at ORNL and set up for general use. A license for the ABAQUS software was purchased, and this finite element analysis program was installed on an IBM RISC 6000 workstation. The ABAQUS portion of the analysis of ceramic-to-metal joints by GTE was rerun to verify its operation. Work to run the full analysis, including the treatment of failure using CARES, is continuing. Also, materials acquired from GTE were prepared into specimens for a variety of experiments aimed at examining the materials' systems they developed in more detail, optimizing brazing conditions, and ultimately improving their mechanical properties.

Further evaluations of the welding and fabrication characteristics of Ni_3Al alloys are being supported by the AIC Materials Program. The ability to produce reasonable quantities (one to several kg/batch) of welding wire is critical to a detailed investigation of the welding characteristics and weld properties of the Ni_3Al alloys. However, the production of wires for use as welding consumables by routine metal-working operations is problematic, owing to the high strength and limited ductility of many Ni_3Al alloy compositions. Wire can be produced by techniques other than conventional rolling and drawing, and several of these alternatives were investigated for making an IC-221W welding consumable material. The wire-making techniques evaluated included approaches based on rapid solidification processing, mechanical cladding, metal-powder-cored tubular wiremaking, and various powder extrusion methods. Also, 10-mm-thick plates of the cast IC-221M alloy were welded together using the GTA process and IC-221W filler metal. The weld contained only minor defects and was sectioned transverse to the weld axis to provide several weldment tensile specimens. Tensile testing indicated that excellent strength was maintained in the weldment up to 900°C, the highest testing temperature used. A small effort was also initiated, in conjunction with an industrial partner, to develop a flux system suitable for making coated electrodes for SMA welding. Part of this project also involves participation in CRADAs with General Motors Corporation (GM), Saginaw Division, and Metallamics to develop Ni_3Al alloys for use in a variety of heat-treating applications. This program involves significant industrial interactions in addition to the CRADAs.

The emphasis of the modeling activities under the ONR Program on residual stresses is aimed at understanding the thermal stresses and metal movements caused by the thermal effects that occur during welding. This program will coordinate with the work that is being performed at Carder Rock Division, Naval Surface Warfare Center, Annapolis Detachment and the National Institute for Standards and Technology (NIST), which aims to experimentally measure the residual stresses developed in a model two-phase material during welding. A coupled thermomechanical model will be developed to evaluate the residual stresses generated in a single- and multi-phase material, due to nonuniform thermal distribution, that are generated during welding. The study will take advantage of the considerable advancement made at ORNL in the realistic prediction of the thermal distributions in the weldment. The predictions of the model will be compared with experimental measurements (using neutron diffraction) of residual stress distributions in the weldment. If any discrepancy is observed, the computational models will be adequately modified. Upon verification, the computational models will be used to study the effects of process parameters, the weld geometry, weld preheat, etc., on the extent and distribution of residual stresses.

In 1992, under the DP CRADA initiative, a multi-lab (MMES, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, and Sandia National Laboratory) program was developed for lightweight materials with GM. The Materials Joining Group has the technical lead for the welding task under the DP-Lightweight Materials Program. The program involves the development of a real-time, on-line control of welding for automotive applications.

The emphasis of the weld modeling subtask under the materials by design CRADA is to develop computational modeling tools for analyzing welded structures. The program involves developing and implementing the necessary modeling tools and user-friendly pre- and post-processing interfaces. The purpose is to develop a simulation software for the design and optimization of production welds. The goal of the effort is to carry out research that will lead to the development of a new and unique material/thermal/fluid/mechanical-coupled software package for predicting weldment behavior during welding. Such a simulation software would result in substantial improvements in the weld quality and reliability and minimize in-service catastrophic failures.

The technical lead for developing the welding technology and procedures, which are in strict compliance with applicable Military Standards for submarine fabrication, continued for the SEAWOLF Project. Fabrication of the propulsor remains nearly on schedule. Analyses and refinement of the processes continue to provide improvements in manufacturing and cost reductions for future propulsors. Additional projects for the Navy are being examined and estimates prepared as they are requested of MMES.

Joining support continued for the ANS Corrosion Test Project, which is examining the oxidation behavior of aluminum alloys under expected thermal-hydraulic conditions. Additional alloys having potential application for this reactor were fabricated into test specimens this year.

The reference blanket attaching-lock design for the ITER Project is multiple-welded connections. A study was conducted to establish the feasibility of the multiple-welded connector or "welded bolt" design. The effort was aimed at welding and cutting prototypic connectors in a mock-up of the 2-cm gap between blanket/shield modules. A special gas metal arc-welding head was designed, fabricated, and successfully tested in the mock-up.

As part of the activities to examine all aspects of the general purpose heat source (GPHS) iridium-clad vent set production at Y-12, welding fabrication by the laser and EB processes was thoroughly reviewed. This included identification and correction of deficiencies in equipment, fixtures, and procedures. Most of the corrective actions have been completed. Technical surveillance will be conducted during 1993 to ensure the continuation of high-quality components.

1.5 MECHANICAL PROPERTIES — *C. R. Brinkman*

The Mechanical Properties Group develops and analyzes data for metals, ceramics, and polymers; qualifies new materials; and provides materials engineering support for ongoing energy- and defense-related programs. During the reporting period, we received support from the following programs: examination of Advanced Liquid Metal Reactor (ALMR) components, 5%; Fossil, 10%; Conservation, 20%; NPR, 25%; SNP, 15%; and miscellaneous, 25%. The overall effort on these programs was in characterizing the elastic, plastic, creep, fatigue, and creep-fatigue properties and studying the influence of environment on the mechanical behavior of base metals, weldments, and ceramics. Our laboratory contains a wide variety of uniaxial and multiaxial equipment for testing materials in air, high-vacuum, and gaseous environments. After statistical and parametric analyses of generated data, we store and/or present it in a form useful to engineers or code developers for design. We serve on several important ASME and ASTM committees developing design rules and test method standards.

Data development and analysis for the materials technology to design and to license MHTGR-NPR nuclear power systems emphasized collection of information on mechanical properties, thermal stability, and behavior of wrought materials and weldments. Structural and steam generator alloys under investigation included 2¼Cr-1Mo (including aged and decarburized material), A533 grade B steel, and Alloy 800. An extensive amount of time was spent evolving test plans and procedures during this period. This program is expected to conclude during FY 1993.

Emphasis was placed on characterization of modified Alloy 800 and associated filler materials in the temperature range of 500 to 800°C for fossil plant applications. Evaluation was continued on nitrogen-bearing stainless steels that had seen up to 100,000 h of service in main stream line applications in support of fossil plant life-extension efforts. Evaluation was completed of materials and design for tube sheets in hot-gas cleanup systems. Efforts were initiated aimed at developing CRADAs for metallurgical examination of bellows and steam tubing. Development was completed on a modified 310 stainless alloy that has a creep strength greater than Alloy 800HT to temperatures of 925°C.

Creep and tensile testing of refractory metal alloys (Nb-1Zr and PWC-11) continued in support of the Space Reactor (SP-100) Program. Test temperatures ranged from 977 to

1427°C under high-vacuum conditions. The work involved tensile and creep testing as well as helping to coordinate work at other laboratories in support of program needs. Determining the effects of irradiation on the tensile properties of rhenium was continued.

Critical to the development of advanced automotive technology using ceramic components (e.g., gas turbines) is the development of a mechanical properties data base for candidate structural ceramic materials. During the period, exploratory tensile, creep, and fatigue tests continued on a number of structural ceramics at both room and elevated temperatures. These tests were conducted with unique specimen grips developed at ORNL, which are now available from a commercial source. Ten creep frames were operational for the testing of ceramic materials for advanced engine development. These systems can test uniaxial specimens and control the load and specimen alignment. A high-temperature, laser-based, noncontacting extensometer developed in this laboratory was used to make highly precise creep-strain measurements. Considerable creep data were generated on silicon nitride and models developed for predicting creep and rupture behavior. Papers were written covering work performed and submitted to various journals for publication.

We served as program monitors for several large programs in private industry aimed at developing the methodology for life prediction of monolithic ceramic components and continued our ceramic mechanical and physical properties computerized data storage program in support of advanced heat engine development. An international symposium was organized covering life prediction of ceramic components operating at high temperatures.

An autoclave facility was developed for fatigue testing of various alloys in hydrogen at pressures up to 35 MPa. The work was in support of National Aeronautics and Space Administration (NASA) activities and involved fatigue testing of Alloy 718 at room temperature. We acted as a round-robin monitor coordinating the work of other laboratories doing similar work for NASA.

We initiated work on determining the high-cycle fatigue properties of metal-matrix composite alloys via a CRADA agreement with GM.

1.6 MATERIALS PROCESSING — *V. K. Sikka*

The Materials Processing Group deals primarily with the development of novel methods for melting, casting, powder making, metal-martix composites and near-net shapes, cleaning of liquid metals, and materials processing. The development of these methods is supplemented with process models. The Materials Processing Group is also developing methods for successful processing of intermetallic alloys such as nickel aluminides, nickel aluminides containing chromium, nickel aluminides containing iron and chromium, iron aluminides, and titanium aluminides. The group has a significant program for the fabrication of iridium sheet to provide iridium containment in support of space and terrestrial isotope power supply systems. It also has the responsibility for transferring to U.S. industry the processing technology for nickel-aluminide and iron-aluminide alloys and other novel fabrication processes being developed. The group is also very active in developing CRADAs with industry.

The Materials Processing Group fulfills the metal processing needs of the other groups in the M&C Division and does work for other divisions of ORNL as well as other facilities operated by MMES. Processing work is also carried out for other national laboratories, universities, and industries. Specific projects worked on and key accomplishments for FY 1992 are listed below:

1. Ductilization and Processing of Iron Aluminides. Iron aluminides are low-cost materials for highly oxidizing and sulfidizing environments. The use of these alloys has been limited because of their very poor room-temperature ductility (≤5%). Several researchers have attempted to improve the ductility of these materials over the last 50 years. Only during 1982 through 1984 were the ductility values of these materials increased to 8 to 9%. During FY 1988 and 1989, the ductility values of Fe_3Al-based alloys have been increased in the range of 15 to 20%. The ductility improvement has been obtained through thermomechanical processing and heat-treatment control. The ductile Fe_3Al alloy won the R&D 100 Award for 1990.

   It was recognized that the environmental effect was the primary cause of low ductility of iron aluminides. The environmental effect is related to the generation of hydrogen through the reaction of aluminum in the alloy with the moisture in the air. The surface-generated hydrogen diffuses into the alloy during straining and causes the hydrogen embrittlement. A systematic study was conducted on the effects of aluminum content on the extent of the environmental effect. The study revealed that the alloys containing ≤16 at. % Al are free from the environmental effect. This information has led to the development of new alloy compositions based on Fe-16 at. % Al. These compositions possess room-temperature ductility values of 25 to 28% in the wrought condition. A patent application on these compositions was filed.

   The iron aluminides, including the new compositions, are now licensed to four companies: Ametek Specialty Metals Division (Eighty Four, Pennsylvania); Hoskins Manufacturing Company (Hamburg, Michigan); Harrison Alloys (Harrison, New Jersey); and Cast Masters (Bowling Green, Ohio).

2. Processing Technology and Mechanical Properties of Nickel-Aluminide Alloys. Castings were identified to be the most needed products for near-term applications of the nickel-aluminide alloys. During FY 1992, the effort continued in optimizing the casting process parameters. These included the pouring temperature, cooling rate, and the mold material. The effort was carried out jointly with PCC Airfoils, Inc. (Douglas, Georgia); Cummins Engine Company (Columbus, Indiana); and the University of Cincinnati (Cincinnati, Ohio). The pouring-temperature and the cooling-rate requirements to minimize casting defects and maximize mechanical properties were established through the joint work between ORNL and PCC Airfoils. A detailed solidification study on the same alloy compositions was completed at the University of Cincinnati. This study provides correlations between the casting-defect characteristics and the solidification conditions. The solidification conditions include the cooling rates, vacuum on degassing, and the use of grain refiners. Good agreements were observed between the correlations developed in the solidification study and the actual castings poured at the commercial caster, PCC Airfoils.

   The cast nickel-aluminide test bars show nearly two orders of magnitude improved fatigue life at 650°C over the commercial nickel-base alloy, IN-713C. However, a potential source for lower fatigue properties in nickel aluminide exists for conditions where it reacts with the casting shell material. The reaction depth is generally 1 to 2 mil and appears as oxide particles. Joint efforts between ORNL and PCC Airfoils are under way to eliminate the near-surface reaction or to minimize it to an acceptable level. The successful completion of this effort will result in the commercial use of nickel aluminide as turbochargers in diesel engines made at Cummins Engine Company.

3. Iridium Processing. The production of defect-free ingots (63 mm diam) of iridium alloy continued during the last year. The extrusion temperature and ratios continued to work effectively for all ingots produced during the last year. The yield of blanks produced from 63-mm-diam ingots continued to exceed 85%.

   To meet the production requirements for iridium, two major pieces of equipment were installed. These included a 150-kW EB furnace and a computer-controlled consumable-arc furnace. For use in iridium production, these furnaces required comprehensive operating procedures and qualification steps. During FY 1992, the operating procedures were completed for both furnaces. Tests are currently under way on the product made in these furnaces. Successful completion of these tests will yield the qualification of these furnaces for iridium production.

4. Sand-casting Facility and Solidification Modeling. A sand-casting facility was added to the Materials Processing Group. It is a complete facility including: blending of sands, mold making, melting, and pouring into the molds. A new 100-lb air-induction furnace was added to this facility to meet the molten-metal requirement for some of the sand molds. The facility is also equipped with temperature monitoring of the molten metal and the computerized data acquisition system (DAS) for monitoring the solidification behavior. The facility has already been used for sand castings of nickel and iron aluminides. This facility is closely coupled with the solidification-modeling capability. The modeling capability includes features such as mold filling, heat flow, and fluid flow. These models are also capable of helping in the development of quality criteria for castings.

5. Superconductor Fabrication. The effort on the fabrication of long lengths of multifilament, high-temperature superconductor material continued during 1992. The primary emphasis was on the development of deformation-processing requirements to yield high-current density. A new process has been identified to produce high-current density ribbons. A patent application for the process was filed. A systematic approach leading to the development of a commercial fabrication process is currently under way.

6. CRADAs. A three-year CRADA was signed with GM-Saginaw Division (Saginaw, Michigan) for the use of nickel-aluminide parts in heat-treating furnaces. As part of the CRADA, ORNL and GM are working jointly to optimize the casting process for the commercial manufacturing of parts required by GM. The CRADA work also includes the development of mechanical properties and microstructures on the cast parts. During FY 1992, two joint casting trials were carried out at Alloy Engineering & Casting Company (Champaign, Illinois), a supplier for GM. The parts cast during these trials have been shown to have the mechanical properties comparable to those developed on small experimental heats cast at ORNL. Efforts are currently under way to finalize the mold requirements, melting requirements, pouring temperatures, and weld repair of castings. The first part from these trials will go into actual furnace testing during March 1993.

The use of nickel aluminide by GM is expected to result in substantial savings in heat-treating production costs.

7. Technology Transfer. Significant effort was spent in the transfer of various technologies to industries. This effort involved communication through telephone calls, technology transfer meetings, and personal visits. A large effort was also devoted toward supplying sample materials to various industries and universities. One additional license on the production of iron aluminide and a CRADA with GM resulted from this effort.

8. Work for Others (WFO). Work was carried out in the Materials Processing Group for Wright Patterson Air Force Base (through Universal Energy Systems), Cummins Engine Company, AMAX, NASA, Southwest Research Institute, Allison Gas Turbine Division, Textron Lycoming, Idaho National Engineering Laboratory (INEL), and several universities.

1.7 NONDESTRUCTIVE TESTING — *D. J. McGuire*

The NDT Group develops new and improved methods and equipment for nondestructive examination (NDE) and characterization of materials and components. Typical projects include theoretical studies and computer modeling, design and development of instrumentation and equipment, development of techniques and test procedures, and transfer of technology to users. The tasks require a broad base of multidisciplinary tools comprising expertise and equipment in ultrasonics, thermal imaging, dye penetrants, eddy currents, and penetrating radiation. Applications of NDT methods are of interest to a number of sponsoring agencies, including the DOE and USNRC. Technical development and support services have also been provided in cooperation with other ORNL divisions and for outside agencies through the WFO Program.

Our work for DOE in ceramic materials has been expanded this year to include two major programs: the Ceramic Technology for Advanced Heat Engines (CTAHE) Program and the Continuous Fiber Ceramic Components (CFCC) Program. In both of these programs, there is interest in NDE applications for flaw detection and materials characterization. For CTAHE, we have concentrated on detection of flaws in monolithic ceramic test samples and engine components using ultrasonic and radiographic methods. We have developed and tested several ultrasonic approaches including high-frequency focused transducer scanning and synthetic aperture focused transducer systems. Radiographic methods have included both film radiography and advanced X-ray computerized tomography (CT). For the CFCC materials, the properties of the interface between the ceramic matrix and the reinforcing fibers are of interest. We are investigating this through ultrasonic nonlinear acoustic analysis. Excellent images of the fiber/matrix geometry have been produced by both CT and digitized film radiographs. We have also made some exploratory analysis of silicon carbide CFCC materials using eddy-current through-transmission.

We continued our component inspection development and support for the DOE SNP Program. We completed and qualified an automated evaluation method for carbon composite component radiographs and continued our inspections of iridium blanks by ultrasonic, dye penetrant, and visual methods. Some progress was made toward automation of the visual inspection method.

Research toward NDE methods for characterization of reactor core structural graphite has continued for the DOE Office of New Production Reactors (ONPR). Our approach to this work involved eddy-current measurements of graphite electrical conductivity for surface and subsurface flaw detection as well as characterization of oxidation erosion.

As a result of recent emphasis on improvement of in-service inspection of aging nuclear power steam generators, our programs for the USNRC have expanded. We have added new computer capability and the ability to analyze field inspection data in the laboratory. We have provided USNRC oversight for a number of industry initiatives for resolution of steam generator inspection issues. We have also designed a new eddy-current probe due for field testing in 1993 that should provide high sensitivity for steam generator tubing flaws while allowing efficient, high-speed inspection rates.

Under U.S. Air Force sponsorship, we completed two studies. One for the development of neural network analysis of eddy-current signals resulted in several presentations and the publication of ORNL/TM-12172, *The LILARTI Neural Network System*. The other involved CT images of asphalt/aggregate mixtures under varying conditions of static load. A portable load machine was mounted to the CT system for the study that will ultimately result in improved asphaltic concrete for airport runways.

For NASA, we have begun studies for flaw detection and service life prediction for ceramic electrolyte tubes used in sodium-sulfur battery cells. In addition to film radiography, which we have demonstrated to be able to detect both hairline cracks and process density variations, we have used an ultrasonic resonance system to characterize the tubes. The resonance system with planned upgrades should prove valuable for testing of a variety of metal and ceramic materials.

A number of other activities have received NDT support through WFO or other laboratory programs. We have continued through ORNL seed-money grants to pursue methods for nondestructive determination of irradiation embrittlement of reactor steel components. This has included both magnetic signature analysis and a new approach using microcrack analysis of localized thermal shock zones. We have begun a project for the Navy to ultrasonically assess machining and grinding damage in ceramic components. We made high-quality radiographs to assist in evaluation of weld porosity in research reactor test fixtures. We continued a service program for eddy-current thickness measurements of oxide layers on aluminum cladding for reactor applications. We are participating with Pacific Northwest Laboratory and the USNRC in a project for statistical evaluation of flaw distribution in the ORNL-Pressure Vessel Research User Facility reactor vessel.

1.8 MATERIALS AND PROCESS MODELING COORDINATION — *T. Zacharia*

In the past year, the M&C Division has become active in several projects involving modeling of materials and processes. With the establishment of the High-Performance Computing Center at ORNL and industry's strong interest in modeling of materials processing activities, there is a significant opportunity for increased involvement by the division in this rapidly growing area. The Materials and Process Modeling Coordination Task was initiated to take advantage of the opportunities in modeling and simulations and to ensure effective coordination among the various modeling projects.

The division was very successful in developing modeling projects under the DP Technology Transfer Initiative. These include modeling of forming, casting, heat-treatment, and welding processes under CRADAs with GM, the National Center for Manufacturing Sciences, and Concurrent Technologies Corporation, respectively. Additionally, the division is providing the technical lead for ORNL in a multi-institutional Automotive Computing Initiative. The objective of this initiative is to assist the U.S. automotive industry in becoming more competitive in the world marketplace, while meeting the broad industry and national goals in energy, environment, safety, and manufacturing by appropriate use of advanced computing and communications technologies.

2. HIGH TEMPERATURE MATERIALS

V. J. Tennery

A major objective of the research in the High Temperature Materials Section is to characterize the microstructure of materials and to understand how the microstructure controls physical and mechanical properties. Another major function is to provide one of the primary interfaces between the M&C Division and materials researchers outside ORNL, who visit the Laboratory as users. Research achievements of this past year clearly exemplify these objectives.

A brief description of the High Temperature Materials Laboratory (HTML) User Program and the accomplishments of the Metallography and Technical Photography Groups follows.

Two new initiatives, the HTML Fellowship Program and the Ceramic Manufacturability Center (CMC), were established in the HTML during this report period. The HTML Fellowship Program was conceptualized and approved as a means of assistance for increasing the number of highly qualified materials scientists and engineers to conduct the advanced R&D necessary in the future. The CMC, a partnership between DOE Offices of Conservation and Renewable Energy, DP, and Energy Research (ER), will focus on the development and demonstration of advanced machining of structural ceramics. A description and summary of the status of these two new initiatives also follow.

2.1 HIGH TEMPERATURE MATERIALS LABORATORY USER PROGRAM — *F. M. Foust*

The HTML User Program became operational in FY 1988. This User Program is the focal point at ORNL for interaction between researchers from industry, universities, and ORNL in their pursuit of developing better high-temperature ceramics.

During this report period, instruments were installed in two new user centers (X-ray Residual Stress and Ceramic Specimen Preparation) that were approved in FY 1990. These two centers are now fully operational.

Instruments located in the six user centers of the HTML (Materials Analysis, X-ray Diffraction, Physical Properties, Mechanical Properties, Ceramic Specimen Preparation, and Residual Stress) were utilized by 77 researchers from 49 institutions (23 industries, 24 universities, and 2 other government facilities). These outside users accrued a total of 5379 user days. There were 148 researchers from MMES, who accounted for an additional 6482 user days during this time period.

A description of the research capabilities available in the HTML User Program is given in the *High Temperature Materials Laboratory, Metals and Ceramics Division, Fifth Annual Report (October 1991 through September 1992)* by Victor J. Tennery and Felicia M. Foust, ORNL/TM-12282 (December 1992). This report also summarizes the nonproprietary research projects conducted at the HTML during FY 1992 by outside users.

Formal user agreements were executed with 15 universities and 15 industries during this report period. To date, 179 user agreements have been executed (80 universities, 99 industry, and 5 other government facilities). These totals include 30 proprietary agreements.

The HTML User Program is funded by the Office of Transportation Technologies, Conservation and Renewable Energy, U.S. DOE.

2.1.1 Materials Analysis User Center (MAUC) — *T. A. Nolan*

The MAUC utilizes electron microscopy and surface chemical analysis techniques to characterize the structure and chemistry of advanced structural materials. The information obtained from these characterizations is used to elucidate the mechanisms that control material performance. During the past year, user activities with researchers from universities and industrial companies have continued at about the same level as during 1991. The electron microscopy facilities are being used extensively, primarily by the HTML staff and outside users. The scanning Auger microprobe is also well utilized. Electron spectroscopy for chemical analysis and secondary ion mass spectroscopy usage has been very low.

Several important new instruments have been added to the suite of user center instruments. A scanning probe microscope incorporating both scanning tunneling and atomic force microscopy modes is operational. This instrument has interchangeable heads that allow the surfaces of large items such as ceramic tensile specimens and metallographically mounted specimens to be imaged with near-atomic resolution. Another major, new addition is a field emission gun (FEG) transmission electron microscope (TEM). The Hitachi HF-2000 200-kV FEG-TEM began beneficial operation in June 1992 (two months ahead of schedule). This instrument adds two major, new capabilities. On specimens having ideal geometry, it provides the highest lateral resolution presently attainable for X-ray elemental analysis; elemental composition of regions as small as 1 nm can be determined, thus greatly enhancing our abilities to analyze ceramic GB compositions. The field emission source illuminates the specimen coherently, thus allowing electron holography to be performed. Electron holograms preserve image phase information (lost in conventional TEM). Utilizing the additional phase information, lens aberration corrections can be made that should result in greatly improved resolution (possibly reaching the 0.1-nm level). Also, magnetic flux quanta can be imaged, and specimen thickness variations of less than 0.05 nm can be determined. The first year of a three-year Director's Fund initiative to develop electron holography has been completed, and we are now routinely taking high-resolution electron holograms on the HF-2000. Dr. E. Volkl, an international leader in electron holography, has joined our staff as a postdoctoral fellow to assist in the holography project.

Both internal and external user research projects have produced significant results during the past year. As was reported previously, analytical and high-resolution TEM have been used to determine mechanisms of creep and fatigue in Si_3N_4 structural ceramics. These studies contributed to the reformulation of a manufacturer's Si_3N_4 ceramic, which greatly improved the high-temperature properties. During the past year, we have continued to develop an understanding of the specific structural and chemical differences that result in the improved high-temperature behavior. The HF-2000 has been used in this endeavor to provide high spatial resolution elemental analyses of GBs. Both high-resolution electron microscopy (HREM) [using the 4000EX] and high-spatial-resolution elemental analysis (using the HF-2000) have been employed to characterize the microstructure of the ytterbia-fluxed Kyocera SN-260 prior to and after high-temperature fatigue testing. This ceramic provides insight into the effects of using a "non-traditional" sintering aid on properties. HRTEM and scanning electron microscopy (SEM) techniques have been used to characterize multi-ion-beam reactive sputtered lead lanthanum titanate thin foils. Changes in electrical properties have been related to the microstructural development as a function of processing conditions. Atomic force microscopy has been used to measure topographical details of small indentions in ceramic materials that will be related to the mechanical properties of the ceramics. The technique has also revealed interesting growth morphologies of chemically vapor-deposited (CVD) SiC in SiC/SiC composites, provided information on the quality of machined Si_3N_4 surfaces, and shown minute features created on Si_3N_4 wear (tribology) samples.

2.1.2 Mechanical Properties User Center (MPUC) — *M. K. Ferber*

A major thrust of the MPUC is to examine the influence of temperature, time, and applied stress level upon properties such as strength, toughness, fatigue, and creep resistance. The major research facilities include: (1) a Flexure Test Facility (FTF) comprising six high-temperature flexure load frames; (2) a Tensile Test Facility (TTF) consisting of eight high-temperature tensile testing load frames, a fiber test machine, a composites test machine, and servohydraulic universal test machine (UTM) equipped with tension/compression grips; (3) a general-purpose testing lab comprising two UTMs; and (4) a mechanical properties microprobe (MPM) [Nanoindenter]. Currently, one of the UTMs is equipped with a ceramic retort so that the high-temperature mechanical properties can be evaluated in inert environments or in vacuum. In the paragraphs that follow, detailed descriptions of flexure, tension, and indentation research facilities are provided, along with appropriate examples of data generated with these facilities.

2.1.2.1 Flexure Test Facility and General-Purpose Testing Laboratory

During this report period, extensive flexure (and C-ring) testing was conducted using the FTF, a UTM equipped with a high-temperature furnace (designated as UTM-A), and a UTM equipped with a high-temperature furnace and ceramic retort for environmental testing (designated as UTM-E). The FTF is dedicated to high-temperature fatigue studies of structural ceramic materials and consists of six test frames each having the capability of loading three flexure samples. For a given load frame, the specimen loading can be specified as a function of time. This feature permits the user to implement a number of standard fatigue tests including (1) static fatigue (time to failure measured as a function of static stress), (2) dynamic fatigue (fracture stress measured as a function of loading rate), and (3) cyclic fatigue (cycles to failure measured as a function of cyclic stress). Fast fracture testing is also possible.

The UTM-A electromechanical tester is an Instron Model 6027 instrument with a load capacity of 200 kN (45 kip). The test machine is currently configured to apply loads up to 10 kN (2245 lb) at test speeds ranging from 1 μm/min to 1000 mm/min. The instrument is controlled using an electronic console consisting of a microprocessor and keyboard. Application programs are entered into the microprocessor memory via floppy disks. Data generated during testing may be displayed on an x-y recorder and/or transferred directly to a personal computer. A high-temperature clamshell furnace capable of generating temperatures (in air) to 1600°C is currently mounted on the 6027 test frame. This instrument is used to measure (1) creep rate as a function of stress for both flexure and compression specimens and (2) flexure and compression strength (including load versus displacement) as a function of temperature. Low-frequency cyclic testing is also possible with this instrument.

The UTM-E electromechanical tester is an ATS Model 1220 instrument with a load capacity of 89 kN (20 kip). The test machine is currently configured to apply loads up to 20 kN (4490 lb) at test speeds ranging from 50 μm/min to 50 mm/min. The instrument is capable of operating in displacement, load, or strain control. A built-in function generator provides for simple trapezoidal waveforms to control the displacement, load, or strain as a function of time. More complicated control waveforms can be generated by a computer equipped with a digital-to-analog converter. Data generated during testing are transferred directly to the computer using an external DAS. The test frame also includes a high-temperature clamshell furnace equipped with a ceramic retort. Both compression and flexure tests may be conducted in air, inert gas, or vacuum to temperatures up to 1500°C.

Studies involving flexure (and C-ring) testing have focused upon (1) the measurement of cyclic fatigue behavior of silicon nitride ceramics as a function of temperature, (2) the effect of microwave annealing of silicon nitride upon the creep and fatigue resistance, (3) the relationship between fracture toughness of whisker-reinforced alumina and crack/whisker orientation, (4) the evaluation of the strength of SiC-SiC ceramic composites, (5) the effect of environment upon the fatigue resistance and retained strength of silicon nitride, and (6) the correlation of flexural creep data with tensile creep data generated for a high-performance silicon nitride.

2.1.2.2 Tensile Test Facility

Eight electromechanical tensile test machines (Instron Model 1380) in the TTF are equipped with the Supergrip hydraulic couplers. The operation of all test machines is controlled with integral, electronic load controllers and function generators that allow three principal test modes: ramp at a controlled rate, ramp and hold at a constant load, and tension-tension cyclic loading. All machines are also equipped with short (100-mm) resistance-heated furnaces capable of 1600°C maximum temperature or 1500°C for sustained testing in ambient air. Six machines are equipped with contacting, capacitive extensometers that have resolutions of 0.1 μm at room temperature and 0.5 μm at 1500°C. A Keithley 500 DAS and IBM-compatible computer are used to monitor or control up to four test stations simultaneously.

A servohydraulic test machine (Instron 1332 with 8500 Series electronics) is equipped with the tension-compression grip system. A unique feature of the servohydraulic test machine is the state-of-the-art digital control system that allows either direct control (load or displacement) over the testing or remote control of testing by an IBM-compatible computer and custom software via a general-purpose interface bus. Reversed cyclic loading can be accomplished at frequencies up to 25 Hz depending upon the maximum displacement.

The test machines described above are designed for testing primarily cylindrical, button-head specimens. Two additional electromechanical tensile test machines (Instron Model 1380) in the TTF provide for the evaluation of the tensile mechanical properties of fibers and flat composite specimens. Fiber testing is achieved through the use of a pneumatically actuated, kinematic fiber-grip system. The water-cooled fiber grips are equipped with flat, titanium grip faces between which the fiber is squeezed without slippage or grip-related damage. The gripping force is adjustable through changes in the applied pneumatic pressure. Fiber gage length can be varied from 25 to 200 mm for room-temperature testing. Gage lengths of 155 to 200 mm are possible for high-temperature testing using a resistance-heated furnace capable of temperatures up to 1400°C for sustained testing in ambient air.

The second electromechanical tensile test machine is equipped with a hydraulically actuated, wedge-loaded grip system. The gripping force applied to a flat composite specimen is adjustable through changes in the applied hydraulic pressure. Specimen lengths can be varied from 175 to 250 mm for room- and high-temperature testing. The resistance-heated furnace is capable of temperatures up to 1500°C for sustained testing in ambient air.

During this report period, extensive studies of the strength, creep, and fatigue behavior of silicon nitride button-head specimens were conducted at temperatures in the range of 900 to 1400°. A major objective of these studies was to measure the temperature and stress sensitivities of the dominant failure mechanisms and then compare the resulting experimental data to model predictions. A major finding from these tests was that when failure was controlled by creep damage generation and accumulation, the fatigue life was uniquely determined by the steady-state creep rate (i.e., Monkman-Grant behavior). A second objective was to verify the expected improvements in creep and fatigue resistance of a hot isostatically pressed silicon nitride that resulted from processing modifications to the intergranular phase.

2.1.2.3 Mechanical Properties Microprobe

The MPM (the Nanoindenter) is a special microhardness tester capable of operating at loads in the microgram range (0 to 20 mN). A high load range (0 to 120 mN) is also available. Unlike conventional hardness testers, it is not necessary to determine the area of an indent optically in order to calculate hardness. Instead, the height of the indenter relative to the surface of the specimen is constantly monitored with a sensitive capacitance gage, thus allowing the depth of an indent to be determined. The unique feature of the Nanoindenter is its ability to measure indent depths to +/- 0.2 nm. The area of the indent is then calculated from a knowledge of the geometry of the tip of the diamond indenter. The load is also constantly monitored with the result that hardness is reported as a function of displacement. Measurements of sample stiffness from unloading data permit a separation of the plastic and elastic components of displacement, and the projected areas for indents can be calculated on the basis of the plastic depth of the indents. The elastic moduli of samples can also be estimated from stiffness data.

Motion of the specimen stage in the x-y plane is also precisely controlled. The indenter can be positioned within 2 µm of any chosen point on the specimen, and a series of indents, separated by steps as small as 0.1 µm, may be made in any geometrical pattern. The entire operation of the system is computer controlled, and one or several series of indents may be specified and carried out without further operator intervention.

During this report period, the Nanoindenter was used to (1) evaluate the plastic and elastic properties of thin films, ion-implanted surfaces, and laser-annealed surfaces; (2) generate load-displacement curves for silicon microbeams; and (3) measure the interfacial properties of fiber-reinforced ceramic-ceramic composites.

2.1.3 Ceramic Specimen Preparation User Center (CSPUC) — *B. L. Cox*

During this report period, the CSPUC was utilized for several in-house programs. Silicon nitride compression specimens were machined for use in the MHTGR-NPR Program. These specimens required very flat, parallel ends and high concentricity. A machining plan was developed, and the specimens were machined on the Junger 4-axis grinder. The specimens were successfully tested in the MPUC. Also, a number of fiber-reinforced silicon carbide matrix composite tubes were machined in conjunction with Virginia Polytechnic Institute for mechanical tensile torsion testing on the CFCC Program. These tubes had a 0.0002-in. tolerance on the OD surface, a length of 8 in., and basically represented an unknown material to machine. These factors contributed to the complexities of this project.

Several enhancements have been made to the equipment in the CSPUC. A Norton hydraulic wheel dresser was designed and installed as a permanent component inside the Junger 4-axis grinder. This has involved extensive planning in mounting the wheel dresser in the precise limited location for the work head to clear the wheel dresser during machining operations and still be able to reach the wheel dresser during dressing operations. This is an innovative technique to automate the wheel-dressing operation in reducing time-consuming setups and give the CSPUC the capability of developing advanced wheel-dressing technology. Planned experiments on automated wheel dressing during machining will begin soon.

A special application to fit Harig wheel arbors onto the Junger 4-axis work head has been developed. It will allow generation of a concentric wheel with an accurate form, straightness, or taper utilizing the computer numerically controlled (CNC) automated wheel-dressing operation on the Junger grinder. This would be very difficult to achieve on the Harig surface grinder alone. A unique arbor adapter for a 0.006-in.-wide diamond-plated slicing blade has been designed to mount on the Harig surface grinder instead of a Buehler cut-off saw. It was used to machine a 0.006-in.-wide slot, 0.354 in. deep, to create a specially designed specimen for use with the high-temperature Moiri interferometry in the MPUC. This specimen was the object of study by a visiting professor during the summer.

A coolant overflow safety shut-off system has been designed and installed on the CNC grinders in the CSPUC. This has increased productivity by allowing safe, unmanned, after-hour usage of the equipment. Other enhancements include the addition of a Silicon Graphics crimson workstation with Pro/ENGINEER solid-modeling software, COSMOS/M finite element-modeling software, CIMSTATION simulation software, and CARES brittle material life-prediction software. The workstation is installed in a computer laboratory and linked via ethernet to the CNC equipment in the CSPUC. The workstation will be used to model ceramic component geometry and optimize design parameters using the finite element and life-prediction software. It will also be used to program and simulate machine tool movement of the CNC equipment in the CSPUC and a coordinate measuring machine (CMM) being installed in the CMC. Actual inspection point information from the CMM will be displayed and evaluated on the workstation. A Macintosh-based machine tool programming system has also been purchased and installed. The system is very user friendly and will be used to program simple part geometries.

A presentation was made on the status and future direction of the CSPUC to the Workshop on Superabrasives and Grinding Wheel Technology for Machining Ceramics in Oak Ridge, Tennessee, on May 28, 1992. This presentation provided a brief description of the existing equipment and the user involvement as well as a plan for future enhancement of existing equipment and expected research tasks. These plans include instrumentation of existing grinding equipment along with the addition of ultrasonic, hydroabrasive, and laser-machining equipment. Research tasks include basic machining studies, grinding wheel development, coolant evaluation, automated machine tool programming, and a closed-loop sensor feedback and control system.

2.1.4 X-ray Diffraction (XRD) and Physical Properties User Centers (PPUC) — *C. R. Hubbard*

The facilities of these two User Centers provide both XRD and thermophysical property measurement techniques to characterize structure, phase content, stability, reactions, and thermal properties of advanced structural materials. The temperature range of the facilities is from room temperature to 1500°C and above. The knowledge obtained is used to improve synthesis, processing, and utilization of advanced materials and to develop models relating microstructure, phase content, and defect concentration to properties and performance. Details of the numerous user research activities have been published in the HTML annual report. A couple of examples are given below, along with a brief description of facility enhancements.

The automation of the xenon flash instrument for room-temperature thermal diffusivity measurement, which provides rapid and more accurate measurements of thermal diffusivity at room temperature, was significantly expanded. A longitudinal bar thermal conductivity cryostat and automation system was assembled, and testing and debugging have begun. This system will provide thermal transport measurements from about 90 to

500 K. Such data, in combination with high-temperature data from the laser flash system, are needed for modeling the contributions of microstructure and defects on thermal conductivity.

The calcination and crystallization of linear organoelemental polymer precursors to oxide ceramics were studied with M. H. E. Martin of Cornell University. This project utilized both the simultaneous thermal analysis and the high-temperature X-ray diffraction (HTXRD) capabilities. The research focused on forsterite and Cr-doped forsterite synthesis from poly(methacrylate) and sol-gel precursors. Cr-doped forsterite is of increasing technological interest because of its potential use as a near-infrared, solid-state tunable laser. Results indicate a correlation between residual carbon in the precursors and their crystallization temperatures. The research resulted in a series of joint publications and presentations and was a major factor in Martin's thesis.

The study of melt/recrystallization and the initial crystallization kinetics of the GB phase(s) in a silicon nitride powder formulation was conducted with Dow Chemical Company, using the HTXRD facilities at 1 atm N_2 to temperatures of 1800°C. Dow provided a position sensitive detector system that reduced the experimental time significantly. Rapid measurements are necessary so that volatilization of yttrium-containing species was limited, and the rapid kinetics could be detected. A special barrier layer to reduce the reactivity of Si_3N_4 with furnace components at this temperature was required. The facilities were successful in measuring the kinetics of melting and crystallization of the GB phases in Dow's Si_3N_4 formulation. A previously unknown high-temperature intermediate GB phase was detected, and its role in sintering is being considered. In addition to observing the α-to-β phase conversion, we characterized the temperature and compatible phases present during the liquid-forming sequence during sintering of oxide-doped Si_3N_4 greenware pieces.

2.1.4.1 Residual Stress User Center (RSUC) — *C. R. Hubbard*

The RSUC was made operational and hosted the first series of users, beginning in March 1992. The facility consists of an XRD system for mapping macroresidual stresses on the surface of ceramic and alloy materials. The system consists of a state-of-the-art Scintag stress and texture 4-axis goniometer equipped with a Peltier-cooled, solid-state detector and an 18-kW rotating anode generator. The system provides for complete flexibility in sample tilt, has excellent accuracy in measurement of peak positions, and provides either divergent or parallel beam operation. To date, 12 proposals for use of the RSUC facility have been received. Recruitment for a professional staff member to augment the group's staff is currently under way.

Projects initiated include: (1) "Residual Stress Measurements in Thermal Barrier Coatings," Cummins Engine Co., Inc.; (2) "Measurement of Residual Stresses in CVD Polycrystalline Diamond Films with X-ray Diffraction," University of Florida; (3) "Measurement of Residual Stress in Ceramic/Metal Laminate Composites," University of Florida; (4) "Measurement of Residual Stress Distribution in Stainless Steel Workpieces Machined by a CNC Turning Center," University of Missouri; and (5) "Characterization of Process-Induced Stresses in Si_3N_4 Tensile Bars," Saint Gobain/Norton Industrial Ceramics Corporation. Much of the preliminary work has shown that the commonly assumed biaxial stress state is not a good assumption and rather that the more general triaxial stress state should be expected. This was particularly evident in the ceramic/metal laminate problem where the residual stresses perpendicular to the layer direction were over 60% as large as the stresses within the plane. Subsequent, microstructural characterization of the ceramic-to-metal interface has shown that the metal was filling voids within the ceramic and producing a complex interface with high tortuosity. This realization led to methods to control the tortuosity and further engineering control of the properties of laminates.

Since XRD samples the residual stresses at or very near the surface, a project to utilize the penetration capabilities of neutrons was previously proposed and approved in mid–1991. The Director's Fund R&D project, "Development and Demonstration of Neutron and X-ray Residual Stress Mapping," was renewed for FY 1992 and 1993. The first half-year was primarily spent building the facilities and performing one test experiment. Progress this last year has included improving the instrumentation, performing a series of demonstration experiments, and developing a proposal for future funding. This project is being conducted in collaboration with the Neutron Scattering Group of the Solid State Division and utilizes an existing triple-axis spectrometer at the HFIR. The first demonstration study was the first-ever comprehensive mapping of the residual stresses within ferritic plates joined with a multi-pass weld. The results will be used to develop and verify models for stresses in multipass weldments. Subsequent studies have included mappings of residual stresses in ceramic-to-metal joints; thermal barrier coatings similar to those proposed for use in diesel engines; and Gleeble bars which simulate welding conditions and are used for mechanical property testing, vibratory stress relief in HY-100 steel, and zirconia-reinforced alumina composites. The latter study is an example of the use of the neutron facilities for the determination of microresidual stresses (also known as pseudomacrostresses). The samples were prepared by K. B. Alexander and P. F. Becher of the M&C Division. These microresidual stress studies were performed from room temperature down to 12 K in order to determine the role of the volume fraction on microresidual stresses and the change in these stresses as a function of temperature. The measurements revealed the transformation temperature for the tetragonal-to-monoclinic transformation, even for a sample with just 10% zirconia. The neutron diffraction results provided quantitative data to support theories of microstress behavior and revealed that only about 25% of the tetragonal zirconia particles in a 40% t-ZrO_2/60% Al_2O_3 composite transform to the monoclinic form, even with cooling to 12 K.

2.1.5 Ceramic Manufacturability Center — *T. O. Morris*

The year 1992 was one of conceptualization and creation for the CMC. The CMC evolved from a partnership of the Conservation Energy (CE), ER, and DP programs at DOE. The partnership program is called "Cost-Effective Machining of Ceramics." ORNL and CE have made floor space available in the HTML for the CMC, and CE provided capital funds for the purchase of a creep feed grinding machine. ER funds support a CRADA with Brown and Sharpe, which will provide a CMM for use in the CMC. DP has provided ceramic CRADA support funds for four CRADAs signed so far, with eight more in development. Y-12 Plant operating funds have been used to relocate existing equipment from the HTML to other ORNL facilities.

The equipment in nine of the ten laboratories to be moved was relocated in 1992. Four manual support machine tools were relocated from Y-12 to the CMC, but no new machines were installed in 1992. The new machines will be on site in early 1993. The CMC is scheduled for delivery in February 1993, the creep feed grinder is scheduled for delivery in March 1993, and the first of the CRADA-provided machines should be on site in early spring.

The objective of the CMC is to develop, in conjunction with U.S. industry, advanced technologies and associated scientific concepts necessary to significantly reduce the cost of machining structural ceramics, with an initial focus on heat engine components. Therefore, the efforts undertaken in the CMC will be very much industry driven, and this will, to a great degree, influence the types of equipment installed in the CMC at any given time. No CRADA development work was initiated in the HTML in 1992. This is to begin with the installation of the new equipment in early spring.

Computerization of the CMC was initiated early in 1992 with the procurement of computer-aided design/computer-aided manufacturing equipment and software. The facility also provides extensive additional computer modeling and graphical capabilities. All of the capabilities and equipment are linked together through a DEC net/ethernet network such that a true "art-to-part" process can be followed in the development of manufacturing processes for lower cost ceramic components.

Presentations on the mission and creation of the CMC have been made to numerous potential industrial CRADA partners and to DOE representatives. A presentation on the CMC was also made at the Workshop on Superabrasives and Grinding Wheel Technology for Machining Ceramics in Oak Ridge, Tennessee, on May 28, 1992.

2.2 METALLOGRAPHY AND TECHNICAL PHOTOGRAPHY — *J. R. Mayotte and J. W. Nave*

These groups provided state-of-the-art metallography, light microscopy, technical photography, and image analysis support to research programs originating within M&C Division; R&D activities at other MMES sites; and research efforts involving industrial companies and universities through user program activities.

2.2.1 Metallography — *J. R. Mayotte*

The Metallography Group performs research in optical microscopy, general metallography, and photography of both alloy and ceramic materials. Metallographic examination is performed in collaboration with materials researchers within the M&C Division, ORNL, other federal laboratories and agencies, and industrial firms. During this reporting period, the group prepared 2224 metallographic specimens. Microanalysis was performed on 200 specimens.

Environmental, safety, and health (ES&H) improvements continued during this period. The process waste system for disposal of specified liquid waste was approved. Specified acids must be neutralized and documented before they are discharged to the process drain. Ineffective laboratory hoods were replaced.

Metallography staff members continue to improve techniques for specimen preparation for both alloy and ceramic materials. Metallographic preparation of cross-sectioned materials for materials characterization continued as a major effort. A computerized system for microhardness data was developed and put into use. This system has the capabilities for storing and retrieving information pertaining to each specimen submitted for microhardness processing.

Tom Geer, Hu Longmire, and Marie Williams joined the group during this period.

2.2.2 Field Metallography and Failure Analysis — *J. R. Mayotte*

Field metallography and failure analysis for ORNL and other DOE installations remains a function of our group. Nondestructive metallographic examination on Chinese steel supported studies that the ORNL Quality Department performed.

2.2.3 Technical Photography — *J. W. Nave*

The Technical Photography Group continues to develop new areas of service that are beneficial not only to the M&C Division, but to all of the MMES facilities.

Our video capabilities are continuing to expand to include recording of training sessions, group meetings, special projects, and all documentations that require video presentations.

In addition to research photography, the group is involved in public relations photography for ORNL and M&C. Technical Photography is responsible for the large (30- by 40- and 40- by 60-in.) photographs that are on display in our hallways and the south canteen by a special process called posterizations.

We are investigating the latest digital imaging technology, and all the capabilities of storing images instead of negatives, and being able to produce higher quality and greater production of various type images that include computerized, photographic images, still photographs, slides, and viewgraphs.

This past reporting period, the Technical Photography staff members completed 1069 photographic work orders that included 25,173 units of photographs, photomicrographs, slides, and viewgraphs in color and black and white.

3. MATERIALS SCIENCE

E. E. Bloom

Research in the Materials Science Section has two primary objectives: (1) to contribute to the fundamental understanding of the behavior of materials and (2) to apply this understanding in the development of improved and new materials for advanced technologies. We accomplish these objectives through close coordination of our capabilities and expertise in theory, modeling, structural characterization, material synthesis, and physical and mechanical metallurgy.

The largest single effort is the research supported by the DOE BES, Division of Materials Sciences. Basic research on the electronic theory of materials (Theory Group), radiation effects (Defect Mechanisms Group), and alloy design (Alloy Behavior and Design Group) provides the foundation of understanding required for the development of high-temperature alloys and neutron-radiation-resistant structural materials. Microscopy and microanalysis research (Microscopy and Microanalytical Sciences Group) and X-ray research (X-ray Research and Applications Group) continually advance the state of the art in tools for structural characterization (TEM and AEM, imaging atom probe, and synchrotron X-ray sources).

We have materials development activities in the following areas: (1) alloys for high-temperature applications (centered in the Alloying Behavior and Design Group), (2) alloys for fusion reactor FWB structure applications (Structural Materials Group), (3) alloys for advanced fossil systems (Structural Materials Group), and (4) modification of the properties of ceramics and polymers by ion implantation and the synthesis of multilayered metal and ceramic structures using molecular beam epitaxy (Defect Mechanisms and X-ray Research and Applications Groups). Each of these efforts draws heavily on the total experience and capabilities of the M&C Division and ORNL.

3.1 THEORY – *W. H. Butler*

Most research in the Theory Group is based on the principle of understanding properties of materials in terms of the underlying electronic structure. The electronic structure of periodic systems is treated using first-principles mixed-basis pseudopotential theory, the full-potential linearized augmented plane wave method, and the Korringa Kohn Rostoker (KKR) method. The properties of substitutional disordered alloys are treated using the KKR-Coherent Potential Approximation, and microchemical interactions in materials are investigated using the Augmented Gaussian Basis atomic cluster technique.

Among the noteworthy results from projects in this reporting period, we summarize the following:

1. **Basic theory and technique**. We developed the Parallel Embedded Cluster Method (PECM) for calculating the energetics of local configurations in a random alloy. We developed a new Partial-Wave Cluster Method for performing first-principles calculations of the energies of molecules and clusters of atoms that should be well adapted for parallel processing. We developed a new technique for treating large systems on parallel processing computers. This technique takes advantage of the relatively local nature of the electronic structure, which is accentuated by finite temperatures.

2. **Phase stability of alloys**. We calculated the phase diagrams of Pd-Rh and Cu-Ni alloys accurately from first principles using a direct Monte Carlo approach based on energies obtained from the PECM.

3. **Mechanical properties of alloys**. We were able to predict the deformation and fracture behavior of Ni_3Si using the results of our first-principles calculations. We also investigated the yield strength anomaly in Ni_3Si.

4. **Defects in alloys**. We predicted the equilibrium concentrations of vacancies and anti-site defects in TiAl, NiAl, and FeAl near-stoichiometry. We also calculated the structure of these defects. We investigated defect clustering in B2 alloys. We investigated the environmental embrittlement of NiAl and the modification of this effect by boron additions. We also investigated the effects of carbon and boron as dopants in Ni_3Si and Ni_3Al.

5. **Transport properties of alloys and layered magnetic systems**. We calculated the electronic structure of several layered magnetic alloy systems that show the giant magnetoresistance effect. The results of our calculations allow a simple explanation of the giant magnetoresistance effect in terms of differential scattering of the up-and-down spin electrons. We also calculated the electrical resistivity of nickel-molybdenum alloys and were able to explain the K-state effect observed in these alloys in which increasing order is associated with increasing conductivity.

3.2 X-RAY RESEARCH AND APPLICATION – *C. J. Sparks*

Major changes occur in the X-ray scattering factors of atoms when X-ray energies are tuned near their characteristic electron binding energies. This unique feature of X rays allows us to select an X-ray energy matched to a particular element for which we want crystallographic and/or chemical information. For example, we have made studies of the site substitution of Fe into ordered Al_3Ti alloys by measuring the intensity of superlattice Bragg reflections that depend on the X-ray scattering factor difference squared. This difference is proportional to the atomic number difference between the Al atoms on the Al sites of the crystal structure and the Ti atoms on the Ti sites. If Fe with a $Z = 26$ substitutes for the Al atoms, $Z = 13$, then the superlattice intensity will decrease. The intensity will increase if Fe substitutes on the Ti sublattice. By measuring the change in intensity of these superlattice reflections as X-ray energy is changed, we can determine in a very sensitive way the relative amounts of Fe on the two sublattices. Iron was found to have an equal probability to substitute for either Al or a Ti atom. The tetragonal lattice form of Al_3Ti was converted to the cubic structure upon the addition of 6 at. % Fe.

We have also used this resonance chemical sensitivity of X-ray scattering (often referred to as anomalous scattering) to study the atomic arrangements of elements in metallic solid solutions and at buried interfaces. Large displacements found between Fe-Fe first-neighbor pairs in Ni-rich Ni-Fe solid solutions supported the high-spin-state theoretical interpretation of the magnetic behavior of these alloys, which relates the Fe magnetic moments to the Fe near-neighbor distance. In another study, this chemical sensitivity was used to locate the Cr atom positions of a buried interface in phase with an Al_2O_3 substrate. Furthermore, the sensitivity of the X-ray scattering intensity to the Cr K near-edge absorption edge spectra allowed the oxidation state to be determined for those Cr atoms in phase with the Al_2O_3 at the buried interface.

The ability to select X-ray energies at our synchrotron beamline is much like isotopic substitution is to neutron scattering. We are now developing methods to combine both X-ray and neutron scattering to unravel the local atomic arrangements in solid solutions such as mixed oxides. Such systems are more amenable to study by combining the two methods.

3.3 MICROSCOPY AND MICROANALYTICAL SCIENCES – *L. L. Horton*

The Microscopy and Microanalytical Sciences Group does research focused on the characterization of materials with advanced AEM, atom probe field ion microscopy (APFIM), and MPM techniques. In addition to developing and applying new techniques to gain a better understanding of scientific and technological issues, the group maintains and develops the equipment required for these characterization technologies. Primary research funding comes from the Division of Materials Sciences, BES. Research is also supported by other programs including Fusion Energy, Conservation, and the USNRC. Group members are directly involved with the research efforts of other groups within the M&C Division including Structural Materials, Materials Joining, and Superconducting Materials.

3.3.1 Electron Microscopy Research – *J. Bentley and E. A. Kenik*

Electron microscopy work supported by the BES Microscopy and Microanalysis Task covers topics from fundamental materials science to technique development, increasingly undertaken in collaboration with Shared Research Equipment (SHaRE) Program participants. Further work on inelastic electron scattering included implications for electron holography (theory) and thermal diffuse scattering-electron energy loss spectroscopy measurements of atomic vibration amplitudes (theory and experiment). Refinement of the analysis of metallic colloids in spinel by plasmon spectrometry dealt with the treatment of surface plasmons. Detailed analysis of parallel-detection electron energy loss spectrometry (PEELS) fine structure was used to characterize the charge state of Fe implanted into SiC. In the measurement of sublattice occupancies in ordered intermetallic alloys with the atom location by channeling-enhanced microanalysis method, a statistical analysis approach was found to suffer from the same adverse effects of ionization delocalization as the traditional ratio approach. Channeling effects in the microanalysis of Ni-Ti and Ni-Ti-Zn oxide spinels and procedures for accurate composition determination were studied in a SHaRE project with C. B. Carter and I. M. Anderson (Cornell University and now University of Minnesota). A comprehensive treatment of a new approach for quantification of energy-dispersive X-ray spectrometry (EDS) data that includes absorption and fluorescence corrections for non-homogeneous specimens of complex geometry was also developed with these collaborators. In additional SHaRE research with C. B. Carter and colleagues (University of Minnesota), a new method was devised for the analysis of thin surface films of an oxide glass deposited by laser ablation onto alumina substrates, and a detailed PEELS study of an oxidized CoO-ZrO_2 eutectic revealed oxygen gradients and dramatic bonding differences in a spinel-like interface phase. In a SHaRE project with R. Sauerbrey and H. M. Phillips (Rice University), the process of excimer laser-induced electrical conductivity and mechanical nanostructures in polymers (polyimide) is being studied by PEELS. Good quality spectra were obtained from this high-temperature (and beam-damage-resistant) polymer and revealed interesting changes in the C:O:N ratios. Two different aspects to understanding the growth of AlN on SiC are being explored in a SHaRE project with R. Davis and S. Tanaka (North Carolina State University). In situ annealing of the 6H SiC substrate was studied by dynamic (video recorded) reflection electron microscopy, and compositional homogeneity in thin films of AlN or AlN-SiC mixtures grown on SiC substrates was studied by PEELS and other AEM techniques. Microcrystalline/amorphous silicon is being studied in a SHaRE project with D. M. Maher and Y. L. Chen, also of North Carolina State University. Microcrystallinity is being quantified by interface plasmons (PEELS) and conical dark-field imaging, and the distribution of "dopants" (B,C, and P) is being characterized by EDS and PEELS.

High spatial resolution AEM was used to study segregation, both in internal projects (jointly supported by BES and the Fusion Energy Materials Program) and in a number of external collaborations. The effects of alloy chemistry, prior thermomechanical treatment, and low-temperature (<300°C) irradiation on radiation-induced segregation (RIS) to GBs in several austenitic stainless steels were investigated. The ability to employ PEELS (rather that X-ray microanalysis) in measuring composition in highly radioactive specimens proved essential for several materials. Several collaborations included AEM measurements of GB compositions in ion-irradiated austenitic stainless steels (SHaRE – G. Was, University of Michigan), (S. Bruemmer, Pacific Northwest Laboratory), and (J-J. Kai, National Tsing Hua University, Taiwan). Another SHaRE collaboration (M. G. Burke, Westinghouse) included AEM measurement of equilibrium and RIS both in type 316 stainless steels and in ferritic pressure vessel steels.

Several other SHaRE collaborations were active, including: measurement of compositional inhomogeneities in 1-2-3 superconductors (Y. Zhu, Brookhaven National Laboratory); segregation to boundaries in AlN ceramics by AEM (D. Callahan, Rice University); in situ studies of nucleation and growth in the Al-Zn system (J. Hoyt, Washington State University); AEM characterization of oxide superlattice structures (D. Lind, Florida State University); AEM characterization of FeCo B2 alloys (I. Baker, Dartmouth College); AEM of iron aluminides (N. Stoloff and A. Castagna, Rensselaer Polytechnic Institute); AEM studies of ion mixing in oxide-oxide systems (C. J. McHargue and D. Joslin, University of Tennessee); and boron distributions by AEM (particularly PEELS) in rapidly solidified Pt-Co-B permanent magnet materials (J. E. Wittig and N. Qiu, Vanderbilt University).

3.3.2 Atom Probe Research – *M. K. Miller*

The main instrument development effort has been the design and construction of a position-sensitive or three-dimensional (3-D) atom probe. The vacuum system was completed for the mapping atom probe (MAP). A second energy-compensated atom probe that uses a reflectron lens was also completed. Further enhancements of the atom probe control and analysis software package and the software for the MAP were made. Two new methods that use moment estimators and maximum likelihood methods to determine the compositions of the coexisting phases in ultrafine fine-scale decompositions from atom probe composition profiles were developed. The determination of the extent of the low-temperature miscibility gap in the FeBe system has been completed. Work continued on the characterization of the scale and composition of α and α' phase that forms during the early stages of phase separation within the low-temperature miscibility gap in the FeCr system. Research on irradiated pressure vessel steels and model alloys was suspended due to the lack of specimen preparation facilities for low-level irradiated specimens. However, the characterization of an unirradiated commercial pressure vessel steel that exhibited an LUS energy was completed, and an investigation (with G.-Brauer, Research Center Rossendorf, Dresden, and P.-Othen, Oxford University) into commercial Soviet type VVER 440 (15Kh2MFA) Cr-Mo-V and 1000 (15Kh2NMFA) Ni-Cr-Mo-V steels was initiated. A study of TiC precipitation in model vanadium alloys has been completed. Solute partitioning and γ' precipitation was characterized as a function of heat treatment in a commercial nickel-based superalloy (X750) used in nuclear applications (with M. G. Burke, Westinghouse). GB segregation and precipitation was characterized and related to the changes in the mechanical properties in boron-, carbon-, and beryllium-doped NiAl.

3.3.3 MPM Research – *W. C. Oliver*

The MPM effort at ORNL has been enhanced through the establishment of a new facility. Specially designed laboratory space has been constructed with precise environmental control to allow the highest quality data to be obtained from these sensitive instruments. The new facility will include five research instruments. These are a Nanoindenter II set up for very high resolution ambient temperature indentation experiments, a Nanoindenter I modified to perform ultra-fine scratch experiments, the high-temperature mechanical properties microprobe (HTMPM), an atomic force microscope, and a Lietz microhardness tester. Although a great deal of effort has gone into the construction of this new facility, significant scientific progress has been made. The accuracy of load displacement-sensing indentation experiments has been established and carefully documented in the open literature. Research efforts to examine the measurement of fracture toughness using indentation experiments and the effects of residual stresses on MPM hardness and modulus measurements are nearing completion. Progress has also been made in the understanding of effects of time-dependent plasticity on the indentation process. Additional progress on this subject will be obtained in the coming year as the HTMPM becomes operational. Finally, a finite element modeling effort has been established and has already had a significant impact on our understanding of these experiments.

3.4 ALLOYING BEHAVIOR AND DESIGN — *C. T. Liu*

The primary goal of the Alloying Behavior and Design Group is to generate understanding of alloying behavior and structure/property relationships in metallic and intermetallic alloys so that the design principles for new alloys to meet specific energy technology needs can be developed. Group activities have focused on four major tasks: (1) understanding of physical metallurgy and mechanical behavior of ordered intermetallics, (2) design and characterization of intermetallic alloys for industrial and energy-related use, (3) development and qualification of iridium alloys for space power systems, and (4) processing of metallic and intermetallic materials by innovative methods (e.g., rapid solidification). The first two tasks are closely related, with emphasis on design of new high-temperature structural materials through control of alloy composition, crystal structure, atomic bonding, microstructure, and processing techniques.

Our theoretical modeling effort aimed at understanding the physical mechanisms responsible for deformation and fracture behavior of ordered intermetallics. The ground-state elastic constants and the shear fault energies of Ni_3Si were determined from first-principles total-energy calculations within the framework of the local-density-functional theory. Based on the calculated driving force in the cross-slip-pinning model, i.e., the combined anisotropy of elastic shear and anti-phase boundary energy, the anomalous yield behavior is predicted in Ni_3Al but not in Ni_3Si. The strength anomaly reported in $Ni_3(Si,Ti)$ is attributed to the increased driving force for cross slip, which is likely due to the increased elastic anisotropy (from $A = 2.0$ to $A = 2.8$) caused by titanium additions. From the calculated Griffith strength and a phenomenological theory relating fracture toughness to ideal cleavage strength, Ni_3Si is predicted to be more ductile than Ni_3Al with respect to cleavage fracture.

To understand the ordering behavior and microhardness in transition-metal aluminides, we have investigated the point defect structure based on first-principles quantum mechanical calculations. For TiAl, the absence of structural vacancies is predicted, and the deviations from stoichiometry are accommodated by the substitutional antisite defects on both sublattices. For NiAl, the defect structure is found to be dominated by two types of defects—monovacancies on the Ni sites and antisite defects on the Al sites. For FeAl, on the other hand, we find a more complex defect structure, which is closely related to the importance of electronic structure effect in FeAl. More importantly, we predict the strong tendency for vacancy clustering in FeAl due to the large binding energy found for divacancies. The available experimental data on defect hardening in NiAl, FeAl, and TiAl are explained consistently in terms of the point defect concentrations calculated at various off-stoichiometric compositions (work done in collaboration with the Theory Group).

Considerable progress was also made in understanding GB fracture in Ni_3Al. By taking the unconventional approach of starting with single crystals of boron-free Ni_3Al, which were cold-rolled and recrystallized to produce crack-free polycrystalline material, we were able to show that the *intrinsic* ductility (~16%) of Ni_3Al is considerably higher than anything previously reported; however, it is severely embrittled by moisture in air (ductility decreasing to 3%). Thus, moisture-induced hydrogen embrittlement (an *extrinsic* factor) is a major reason for the poor ductility commonly observed when Ni_3Al is tested in air ($2Al + 3H_2O \rightarrow Al_2O_3 + 6H$). An even more dramatic effect is seen when a small amount (0.3 at. %) of zirconium is added to Ni_3Al: room-temperature tensile ductilities of 8% in water, 12% in air, and 50% in (dry) oxygen. The ductilities observed in oxygen are comparable to the highest ever ductility observed in boron-doped Ni_3Al. Fracture was predominantly intergranular in both alloys, regardless of ductility and test environment. However, this does not mean that the GBs in Ni_3Al are "intrinsically brittle." On the contrary, the extensive ductilities that can be obtained in dry environments indicate that the GBs in Ni_3Al are actually quite strong and able to withstand considerable plastic deformation before final fracture. In contrast to boron-free Ni_3Al, boron-doped Ni_3Al exhibits excellent ductility at room temperature, independent of test environment. Therefore, a significant portion of the beneficial effect of boron must be related to suppression of environmental embrittlement. However, boron must also enhance GB cohesion—because it changes the fracture mode from intergranular to transgranular. Likewise, zirconium also increases the resistance of Ni_3Al to GB fracture—perhaps by increasing GB cohesion. However, Auger analysis shows no zirconium segregation on the GBs of Ni_3Al, making it unclear how such segregation might actually affect GB cohesion.

The alloy $(Co_{85}Fe_{15})_3V$ with the $L1_2$ crystal structure is also prone to environmental embrittlement. Specimens tested in air have a tensile ductility of only 6.3%, whereas specimens tested in vacuum and oxygen show ductilities of 18.8 and 24.2%, respectively. All of these tests resulted in intergranular fracture. With the addition of 200 wt ppm of boron, the environmental effect on tensile ductility of $(Co_{85}Fe_{15})_3V$ is completely eliminated. Specimens tested in distilled water, air, vacuum, and oxygen all show a tensile ductility of ~35% and a transgranular fracture mode. The role of boron in eliminating environmental embrittlement of $(Co_{85}Fe_{15})3V$ appears to be the same as for Ni_3Al in which boron is known to segregate to GBs and increase ductility by suppressing intergranular fracture. Boron occupies defect sites at the GBs, which probably prevents the embrittling hydrogen atoms from penetrating and accumulating there. In addition to eliminating the environmental embrittlement effect, boron also enhances the GB strength of $(Co_{85}Fe_{15})_3V$.

The crack-propagation behavior and fracture toughness at room temperature of extruded and heat-treated NiAl and FeAl were examined by testing chevron-notched, three-point flexural specimens at constant crosshead speeds. In Ni-50 at. % Al, sudden load drops occurred repeatedly, indicating run-arrest crack propagation. The fracture resistance was not found to depend on the crosshead speed. Iron additions of up to 1 at. % and boron additions of 0.01 at. % did generally not improve the fracture toughness. By contrast, crack propagation in Fe-40 at. % Al occurred in a stable manner. In agreement with the environmental sensitivity of this intermetallic alloy, fracture resistance did depend on the crack-propagation velocity, indicative of the kinetic nature of this process. While the crack-growth resistance of iron aluminides was reduced by changing the aluminum content from 40 to 45 at. %, it was increased significantly by small additions of boron.

Several alloys based on the Fe-28Al-5Cr (at. %) composition were produced to study the effect of alloying with Mo, Nb, Zr, B, and C on microstructures, mechanical properties, and weldability. Optical microstructures were examined before and after heat treatments of 1 h at 750°C, as well as selected higher temperature anneals. Tensile properties at room temperature and 600°C and creep-rupture properties at 593°C and 207 MPa were determined and correlated with alloying additions. Judgments as to weldability of selected alloy compositions were made by determining the hot-crack susceptibility. The results indicate that the properties of iron aluminides are very sensitive to alloying additions. Some combinations of the above elements resulted in refined grain sizes, increased recrystallization temperatures, and strengthening of the base alloy (through solid-solution and formation of precipitates) in both tension and creep-rupture. Increased strength, however, was produced at the expense of room-temperature ductility and weldability. The results suggest that the design of useful iron-aluminide compositions will depend on the application, with the composition being modified to provide either room-temperature ductility and weldability or strength, as prescribed by the intended application.

Binary Fe_3Al alloys have very poor creep resistance, but the addition of 1 to 2 at. % Mo or Nb improves the creep life and reduces the minimum creep rate, with niobium being the most effective ternary addition. The improvement in creep life of the Fe_3Al+1Nb is the result of a combination of factors that include GB strengthening, resistance to dynamic recrystallization during stressing, precipitation strengthening, and changes in the formation and mobility of the dislocation network. Correlation of optical, scanning electron, and transmission electron microscopy data suggests that the brittle intergranular failure found in Fe_3Al after creep testing at 550 to 650°C is related to weak, high-angle GBs and to formation of subgrain boundary arrays, reducing the ability of dislocations to glide or multiply to produce matrix plasticity. The addition of niobium results in a strengthening of the GBs by solid-solution effects and formation of fine matrix MC precipitates that pin dislocations and thereby strengthen the matrix. The resulting ductile failure mode and increased creep-rupture strength and life in the Fe_3Al+1Nb alloy suggest that the mechanisms governing failure during creep can be controlled by macro- and microalloying effects.

Work on further development of Fe-28Al-(2 to 5)Cr Fe_3Al-type base alloys has been conducted under the auspices of coordinated efforts between the FEM Advanced Research and Technology Development (AR&TD) and AIC Materials Programs, with involvement of several different groups in the division. Our contributions to this effort have been: (1) identifying microalloying elements that improve high-temperature creep-strength at 600 to 650°C, (2) identifying microalloying elements that improve weldability, and (3) identifying processing/heat-treatment/microstructure conditions that provide the best combination of room-temperature ductility and high-temperature strength in Fe_3Al alloys. This year, several alloys have been designed with significantly improved high-temperature strength and weldability as good as type 316 stainless steel.

Work on FeAl-type B2-phase alloys has continued for structural, as well as for weld-overlay cladding, applications. For structural purposes, compositional modifications and heat treatments have been identified that produce a significant precipitate-strengthening effect that enhances creep-resistance at 600°C. Microstructural analysis and properties studies also indicate that processing/heat-treatment avenues exist for better combinations of room-temperature ductility and high-temperature strength. For weld-overlay applications, a growing family of similar Fe-36Al alloys has been identified with good weldability that is comparable to 300 Series austenitic stainless steels. Preliminary experiments with weldable FeAl alloys weld-deposited on commercial steels (type 304L and 2-1/4Cr-1Mo) indicate that with appropriate pre- and postweld heat-treatments, crack-free FeAl weld-overlay cladding applications are feasible (work done in collaboration with the Materials Joining Group).

This year, a systematic effort to obtain the physical properties data base necessary for engineering applications of iron and nickel aluminides began, together with the X-ray Diffraction and Physical Properties Group, under the sponsorship of the AIC Materials Program. So far, this effort has measured thermal expansion coefficients of FeAl, Fe_3Al, and Ni_3Al ordered intermetallic alloys and is beginning thermal conductivity and diffusivity measurements. FeAl (Fe-36Al) and Fe_3Al (Fe-28Al) alloys show significantly more expansion than type 316 austenitic stainless steels above 600 to 800°C but similar expansion at lower temperatures; thermal expansion of FeAl alloys is slightly greater than that of Fe_3Al alloys. The thermal expansion of Ni_3Al alloys (IC-221M) is about the same as that of the nickel-based superalloy 713C at low and high temperatures.

Besides having potential for high-temperature structural uses, NiAl also undergoes a martensite phase transformation similar to that in other intermetallics that show a shape-memory effect. Because of the desirability to produce a shape-memory alloy with transition temperatures in the range of 100 to 200°C, which would have many practical applications, an investigation was begun to develop ductile shape-memory alloys based on NiAl. This investigation is under the auspices of a CRADA with Eaton Corporation and Carpenter Technologies. Through recovery of indents, we were able to demonstrate that the brittle binary Ni-36Al alloy does exhibit a shape-memory effect. By alloying with boron, iron, and by controlling the Ni/Al ratio, we have developed alloys with 7% room-temperature ductility, martensite and austenite transition temperatures of up to 160 and 190°C, respectively, and a bend shape-memory recovery. The alloy is prepared by quenching in a composition that then undergoes a repeatable B2-to-martensite phase transformation. Studies of the phase stabilities have shown that the alloy retains the appropriate phases and the 7% room-temperature ductility after 1 h at 400°C. However, after 10 h at 400°C, sufficient Ni_5Al_3 forms to substantially reduce the ductility and interrupt the shape-memory effect. Further heating results in phase separation to the B2 and $L1_2$ phases. A melt-spinning method for directly producing wires has been developed which results in wires 0.25 mm in diameter and 2 m long that exhibit the shape-memory effect.

Reactive sintering is a novel and attractive process to produce ordered intermetallic alloys. In order to reduce alloy porosity and control reaction kinetics, reactive sintering of Ni_3Al was performed with uniaxial compressive stresses ranging from 0 to 120 MPa, using elemental powders with the stoichiometric composition preheated to 620°C in vacuum. It was shown that both compressive stress and heat flow strongly affected the reaction process and, hence, the structure and density of reaction-sintered products. Without compression, reaction-sintered products had a relative density up to 98% and were mainly composed of Ni_3Al with uniformly distributed fine pores and large shrinkage cavities located in the center. Green density has little effect on densification. When a green compact self-ignited under a pre-loaded compressive stress (50 MPa), a highly densified product (relative density as much as 99.3%) was obtained. In addition, the product, which was composed of Ni_3Al, NiAl, and Ni, did not contain large shrinkage cavities. Postsintering at 1100°C results in a single-phase Ni_3Al structure with a fine grain size.

Since Ni_3Al intermetallics exhibit high fracture toughnesses and excellent high-temperature capabilities, they have significant potential in the toughening of alumina ceramics. Since processing of Al_2O_3 composites is facilitated by good wetting of the Ni_3Al, compositional modifications of Ni_3Al with the aim of improving its wetting behavior are being examined. Adherent beads of Ni_3Al alloys with wetting angles below 80° have been produced by annealing in vacuum at 1450°C. Furthermore, specimens consisting of thin Ni_3Al layers (typically 150 mm) sandwiched between Al_2O_3 discs have been fabricated by hot-pressing at 1450°C. The toughening provided by the Ni_3Al film is assessed in flexural tests with chevron-notched specimens. Presently, the reproducibility of this technique, which will allow the screening of the different Ni_3Al materials developed, is being assessed.

A process was developed whereby a stream of molten material is injected into a layer of rotating liquid coolant. The product is a wire slightly smaller than the crucible orifice. The method is rather complicated for most materials because it is difficult to maintain liquid jet stability due to the low viscosity of metals. If a layer of oxide or other compound can be made to form on the surface of the liquid stream, the jet may stay stable long enough to solidify into wire within the coolant layer. A number of wires of shape-memory alloys containing Ni-Al-Fe were produced by this method. For the shape-memory alloys, when certain critical processing parameters were followed, the aluminum reacted to form a thin layer of oxide on the surface of the jet, preventing its breakup. The wires were generally ductile, and coils wound with inside diameters ranging from 3 to 10 mm exhibited the shape-memory effect.

The melt spinning process prototype, funded by the Development Division at Y-12, produces lithium hydride flakes and powder. The highly reactive material is kept under a protective atmosphere of argon and hydrogen throughout the operation, from unloading crushed bulk material to transferring the product into shipping containers. Large quantities of stoichiometric, fine-grained flakes or powder are produced directly from the melt without intermediate processing. The operation is semi-continuous in that the feed material and the processed flakes can be inserted and removed without cooling the melt crucible or opening the chamber. Powder compacts, prepared from these flakes by the Special Materials Processing Group at Y-12, have densities of >99% theoretical density. Examination by SEM reveals that the flakes consist of fine, equiaxed, columnar grains oriented perpendicular to the wheel/flake surface.

Ir–0.3 wt. % W alloys containing nominally 60 wppm thorium have been developed at ORNL for cladding plutonium oxide fuel in RTGs. The thorium is added to provide adequate high-temperature ductility for post-impact containment of the fuel in case of an accident. Our current research is aimed at finding suitable substitutes for thorium, which reduces the weldability of iridium. Based on physical-metallurgy considerations, we selected cerium, yttrium, lutetium, and boron for our initial alloy development efforts. Our preliminary results show that, while cerium is as effective as thorium in refining the grain size of iridium, it is not as effective in improving GB cohesion. On the other hand, we have discovered that boron (at a level of 68 wppm) is quite effective in suppressing GB fracture and improving the ductility of iridium. Therefore, a promising new approach would be to add boron to improve GB cohesion and cerium to get grain refinement, thereby replacing thorium completely (work done in collaboration with the Materials Processing Group).

In addition to the iridium alloy development effort, our group also conducted iridium alloy qualification and characterization studies as part of the SNP Program. Included in this task were high-temperature tensile impact testing, grain growth studies in vacuum and low-pressure oxygen, sigmajig weldability testing, and construction of a new high-temperature tensile impact tester capable of testing iridium alloys at 1000°C and extension rates of 60 m/s.

This year, the group has been involved in the development of new CRADAs with U.S. industries. The work includes providing material microcharacterization support necessary to understand the mechanical properties of three materials: (a) high-strength steels, (b) wear-resistant aluminum alloys, and (c) metal-matrix composites.

3.5 DEFECT MECHANISMS — *L. K. Mansur*

Particle irradiation is a dimension of materials science that, like temperature, potentially affects all processes and properties. Research in the group covers the science underlying the effects of displacement and ionization-producing particle fluxes on materials. The two specific areas on which the work currently focusses are the behavior of structural materials for fission and fusion reactor applications and the development of new materials properties by ion beam treatments. Theory and a variety of experimental techniques are combined to attack major research issues.

3.5.1 Radiation Effects

The primary research is on the mechanisms of pressure vessel steel embrittlement. Part of this work is focussed on questions surrounding embrittlement of the HFIR pressure vessel, but the work is also broader, covering the more general aspects applicable to power RPVs, support structures, and other components.

We have mounted a comprehensive experiment to study the effects of dose rate. This covers a wider range of dose rates than any previous study. Tensile specimens of ferritic steels are presently being irradiated in the High Flux Beam Reactor at Brookhaven National Laboratory (BNL) and the Ford Reactor at the University of Michigan to cover intermediate and low dose rates. Specimens for the highest dose rate have already been irradiated in the HFIR flux trap and have yielded an excellent set of data of benchmark quality. These data span a wide range of fluence and include both commercial steels and iron-base model alloys with selected minor alloying additions. In addition to serving as a cornerstone for the dose rate experiments, these HFIR-irradiated specimens have provided valuable information on impurity effects. It was found that copper at a level of 0.3 wt % and nickel at 0.7 wt % cause increases in the degree of radiation strengthening in binary Fe-Cu and Fe-Ni alloys but that these alloying additions at levels up to 0.22 and 3.3%, respectively, cause no increases in radiation strengthening in the commercial alloys.

In connection with these neutron experiments, we have made the first comprehensive neutron dosimetry experiment at the vessel in the surveillance site from which much of the HFIR vessel embrittlement data were obtained. Prior to this experiment, the only measurements of neutron fluxes at the pressure vessel were those obtained from activation of Ni and Fe in stainless steel monitor wires carried in the surveillance packages, which yielded the fast flux >1 MeV. Thermal fluxes were calculated and, originally, had suggested a strongly thermalized spectrum; this had made the neutron spectrum a major suspect in the embrittlement. However, more recent calculations indicated that the spectrum at the site in question was not thermalized. To resolve this issue, the dosimetry experiment was focussed on the thermal flux. Measurements from five different thermal flux monitors all agreed and verified the recent calculations. Measurements of the fast flux from Ni wires were also in agreement with the recent calculations of fast flux and with measurements from the stainless steel monitors in the surveillance packages. Surprisingly, the fast flux measured by Be and Np monitors in the experiment was 15 times larger than that measured by the Ni monitors, possibly suggesting that the spectrum may contain a hitherto hidden population of neutrons in the range 0.5 to 2 MeV, just below the threshold energies for recording by Ni and Fe monitors. Work is under way to resolve this question.

In related work, we are also conducting irradiations of aluminum alloys to explore the possibility of radiation-induced softening at low fluences. The alloys under study include cold-worked and precipitation-hardened alloys including variants and thermomechanical treatments where no irradiation response data are available. The possibility of irradiation softening of aluminum alloys has been suggested by isolated experiments of other researchers but has not been confirmed in any systematic study. Possible irradiation-induced changes in the strength of aluminum alloys are relevant to the ongoing design and future performance of the ANS.

In the related area of theory and modeling, our work indicates that point defect clusters, in addition to various types of precipitates, could contribute significantly to low-temperature embrittlement. However, the dislocation barrier strength attributable to the point defect clusters has been identified as a major source of uncertainty. An experimental program is being initiated to measure these barrier strengths. Ion irradiation will be employed to create specific microstructures. The defect cluster density and size distributions will be measured by TEM, and mechanical property changes will be measured using a low-load nanoindentation technique. The correlation of measured hardness with the observed microstructures will permit the calculation of the required dislocation obstacle strengths.

The use of molecular dynamics (MD) to simulate the formation and evolution of displacement cascades has led to significant advances in the understanding of primary defect formation. However, most MD work has focused on face-centered cubic (fcc) metals such as copper, since adequate interatomic potentials were developed first for these materials. Since many iron-based alloys of technological interest, e.g., pressure vessel steels, have a body-centered cubic crystal structure, we have begun MD investigations using an interatomic potential for iron that was recently developed at the University of Liverpool. The goal of this work is to characterize the evolution of displacement cascades as a function of primary knock-on atom (PKA) energy and temperature. This work is being carried out in collaboration with researchers from the University of Liverpool and the Harwell Laboratory in the United Kingdom. The ability to conduct simulations of high-energy cascades (PKA energy > 5 keV) is limited by the cost of computer time, but two 10 keV cascades have so far been completed at ORNL. A number of low-energy cascades have been completed at Liverpool. Preliminary analysis indicates that some of the general trends observed in fcc simulations are also seen in iron, e.g., the defect production efficiency decreases as the cascade energy increases. However, the fraction of the residual point defects that are observed to be in clusters appears to be reduced in iron when compared to copper.

In work supporting the fusion reactor materials program, the phenomena of radiation-induced conductivity (RIC) and radiation-induced electrical breakdown (RIED) have been identified as potentially limiting the use of ceramic insulators in near-term fusion reactor designs. While RIC has been investigated extensively, the observation of RIED is relatively new, and the defect(s) responsible for it have not been identified. A series of ion irradiations is being planned with the goal of determining which of the potential defect structures is responsible and to explore the temperature and damage rate sensitivity of RIED. Multiple-ion beams will be used to examine the relative importance of ionizing and displacive irradiation. The initial experiments will focus on alumina.

In work also related to fusion reactor materials, we have carried out research to obtain basic information on helium behavior in ceramics. Helium will be produced in large quantities by (n,α) transmutations in future fusion reactors. For the present work, the lattice site of ^{3}He that was implanted by accelerator has been characterized with ion channeling for α-Al_2O_3, MgO, $MgAl_2O_4$, C (diamond), Si, α-SiC, TiO_2, SiO_2, ZnO, and YSZ. Except for MgO, helium implanted at room temperature occupies a distinct interstitial location. The crystal structure of most polyatomic ceramics incorporates interstitial sites that are partially filled by cations. The diamond crystal structure also possesses tetrahedral interstices that are vacant. Channeling evidence suggests that helium traps at these positions for room-temperature implantation. MgO does not contain structurally vacant interstitial positions, although vacancies created by displacement damage influence the results. The temperature dependence of the trapping has been studied for α-Al_2O_2, in which helium detrapped from octahedral interstices to random positions (e.g., to create cluster precursors to void formation). The dose dependence has been examined in α-SiC, where it was found that helium increasingly occupies random positions with increasing fluence.

3.5.2 Materials Modification

Opportunities for enhancing materials properties and creating new materials by ion beam treatment are being pursued. In the past year, several significant accomplishments have resulted from this research. The primary emphasis has been on improving the surface-sensitive mechanical properties of polymers. At the same time, related work was also carried out on austenitic model alloys and more complex stainless steels. The technological potential of research results from the polymer work was the basis for the group being honored with a 1992 R&D 100 Award presented by *R&D Magazine*.

Large increases in hardness and wear resistance have been found to result from single- and multiple-ion bombardment of a variety of simple (e.g., polyethylene) to high-performance polymers (e.g., polyimides.) We have made a contribution to hardness measurement techniques for polymers by establishing measurement protocols for applying nanoindentation testing to these viscoelastic materials. We have made significant progress in characterizing the structural changes induced by energetic ion beams and in understanding the mechanisms leading to the enhanced properties. Special deuterated polymers were prepared, and the release of molecular species by polymer chain scission was characterized as a function of ion beam energy and species. A strong correlation was established between measured hardness and the relative contribution of energy loss by ionization/excitation (as contrasted with displacement), and this has led to insights into the molecular mechanisms responsible for the large changes in mechanical properties. The three-year internal exploratory studies program, on which much of this work was supported, has led to numerous publications and industrial interactions. This, in turn, has led to follow-on work supported by DOE programs and an outside industrial partner.

Unique results also have been obtained as a result of surface modification of metallic alloys. Simultaneous B^+ and N^+ ion implantation, as well as single-beam Ar^+ implantation, have led to substantial improvements in creep properties of a ternary Fe-13Cr-15Ni alloy. The effects of the same ion beam treatments on a complex Fe-13Cr-15Ni-2Mo-2Mn-0.2Ti-0.8Si-0.06C alloy have also been explored. Constant-load creep tests were performed in vacuum. All specimens failed by intergranular fracture, with the ternary specimens failing by void coalescence at GBs and the complex alloy specimens failing by GB sliding. The B^+,N^+ implanted ternary showed an increase of approximately 75% in creep life. This was attributed to delayed slip band and void formation at surface GBs. The dual B^+,N^+ implantation also increased the creep life of the complex alloy by about 70%, which was related to strengthening of surface grains and reduced GB sliding as suggested by reduced ductility of the implanted specimen. The Ar^+ implantation increased the creep life of the ternary by about 45% but slightly reduced that for the complex alloy. These results are interpreted in terms of the competing effects of weakening of GBs by Ar bubbles and strengthening caused by radiation damage and by Ar bubbles in the matrix, with the former predominating in the complex alloy and the latter in the ternary alloy. The large increases in creep life achieved by ion beam treatments that affect only about 10^{-3} of the specimen volume are considered significant and will be the subject of future research.

3.6 STRUCTURAL MATERIALS — *A. F. Rowcliffe*

The primary focus of the group is the development of structural materials for fusion and fission reactor applications. The multi-national program to design and build the ITER is expected to begin a detailed engineering design phase in 1993. During this phase, "ITER credits" will be awarded to various groups for all aspects of engineering, design, and technology R&D. During 1992, we adjusted our program to be in a position to bid strongly for ITER materials R&D support in three areas: (1) structural alloys for the first wall and shield, (2) heat sink materials for the divertor, and (3) ceramic materials for diagnostic systems and for ion cyclotron heating systems. In non-ITER-related areas, work is continuing on reduced-activation materials based on ferritic-martensitic ferritic-bainitic stainless steel systems on silicon carbide composites, and on vanadium alloys.

In the area of austenitic stainless steels, two spectrally tailored capsules were prepared and inserted in HFIR removable beryllium (RB) positions. These experiments reproduce the temperatures, damage rate, and helium generation rate characteristic of ITER. Candidate U.S. and Japanese alloys will be irradiated to the goal ITER fluence of ~20 displacements per atom (dpa); measurements include tensile, irradiation creep, fatigue, electrochemical, and swelling properties. Earlier irradiation experiments to a dose of ~8 dpa showed that large reductions in work-hardening capacity occur in the temperature range 100 to 350°C. To assess the impact on fracture toughness, three HFIR capsules were irradiated in target positions to a dose of 3.5 dpa. The capsules, which contain approximately 130 compact tension specimens fabricated from European, Japanese, and U.S. alloys, operated at 100 to 125°C and 250 to 300°C. Unloading compliance testing coupled with tensile testing, scanning fractography, and TEM is in progress.

The leading candidate material for the ITER divertor heat sink is the oxide-dispersion-strengthened copper alloy, GLIDCOP Al-25. To provide some relevant irradiation performance data, a collaborative experiment in the Russian SM-3 reactor has been designed with the Efremov Institute, St. Petersburg. This experiment is spectrally tailored to adjust transmutation rates to fusion levels. It will provide fracture toughness, creep, swelling, and tensile data at 100, 250, and 350° C at doses of 0.5 and 5.0 dpa. Apart from specimen fabrication, all the work will be carried out under subcontract in Russia.

Ceramic materials are widely used in the diagnostic systems, beam-heating systems, and the shield region of ITER. These applications provide a major technological challenge because of the damaging effects of ionizing and displacive irradiation on the electrical properties of ceramics. A series of dielectric property measurements at a frequency of 100 MHz was completed on seven different ceramic insulators during pulsed-neutron irradiation at room temperature. Exposure to irradiation fields relevant to the first wall of ITER caused significant increases in the loss tangent in all seven materials (sapphire, two grades of polycrystalline Al_2O_3, single $MgAl_2O_4$, Macor machineable ceramic, and polycrystalline AlN and Si_3N_4), whereas the dielectric constant was nearly unchanged. After the irradiation pulses, the loss tangent of all seven materials quickly recovered to a value near the preirradiation level. There was no correlation between the preirradiation (or postirradiation) loss tangent and the loss tangent measured during the irradiation pulse. In situ tests conducted with and without Pb shielding showed that the large, prompt increases that occurred during the irradiation were associated with radiation-induced electrical conductivity increases (ionizing radiation), as opposed to displacement damage produced by neutrons. These experiments highlight the necessity of performing in situ property measurements during irradiation to qualify ceramic insulators for aggressive radiation environments.

Calculations of the effect of ionizing and displacive radiation on the thermal conductivity of alumina at high temperatures were completed. These calculations show that the phenomenon of RIC, which gives rise to a prompt increase in the electrical conductivity and dielectric loss tangent, does not give rise to a corresponding prompt decrease in the lattice thermal conductivity due to phonon-electron scattering. These calculations also predict the significant reduction expected in the lattice thermal conductivity with increasing dose due to the scattering of phonons by radiation-produced vacancies, voids, and precipitates. These accumulated dose effects have implications for the design of microwave windows for fusion reactors. Calculations of the effects of radiation on the thermal conductivity of alumina at low temperatures were initiated.

Cross-section TEM was utilized to examine the radiation-induced microstructural changes in oxide ceramics after irradiation with a wide variety of ion beams. It was observed that the microstructure associated with irradiation was dependent on the mass of the ion beam. The cross-section microstructural results have been correlated with the calculated depth-dependent partitioning between ionization and displacement damage. This correlation indicates that defect clusters do not form in $MgAl_2O_4$ if the ratio of energy deposited into electron ionization to atomic displacements is greater than about ten. This ratio of ionization to displacement-absorbed energies is comparable to the value associated with fission and fusion reactor irradiation environments and provides independent support for the observed resistance of $MgAl_2O_4$ to form defect clusters during neutron irradiation. The corresponding derived ratio needed to suppress defect cluster formation in MgO and Al_2O_3 is 500 to 1000, which is much higher than the ionizing-to-displacive radiation ratios associated with fission and fusion reactors. Hence, the correlation predicts that defect cluster formation should occur readily in Al_2O_3 and MgO during neutron irradiation, in agreement with experimental observations. Additional microstructural evidence obtained on the ion-irradiated ceramic specimens suggests that the physical mechanism responsible for the lack of defect clusters in highly ionizing radiation environments is associated with ionization-enhanced diffusion, which promotes annihilation of the point defects created by displacement damage during the irradiation.

The use of silicon carbide composites for fusion reactors offers the potential benefit of a very low-activation structural material with high-temperature strength. The effects of radiation on the SiC/Nicalon™ composite system are being studied. It was shown that the ultimate strength of this system is degraded by 25% following low-temperature neutron irradiation to 1 dpa. The fiber pull-out is also significantly increased. Through the application of the thin-section fiber push-out method to unirradiated and irradiated composites, it was shown that both the decrease in composite strength and the increase in fiber pull-out are due to a reduction in the fiber/matrix interfacial strength. Specifically, the mean stress required to debond the fiber from the matrix, which can be related to the composite strength, was reduced from 64.8 to 7.2 MPa. The mean stress required to slide this debonded fiber through the matrix, which is related to the fiber pull-out, was likewise reduced from 19.6 to 6.9 MPa.

TEM of the irradiated composites has shown that the irradiation-induced degradation is caused by fiber shrinkage causing partial debonding of the interface. The emphasis of the development of SiC composites therefore hinges on the ability to produce an SiC fiber that will exhibit little or no shrinkage during irradiation. A wide range of newly developed commerical fibers, as well as developmental, fully dense, SiC fibers, is being studied. Composites are currently being fabricated for irradiation testing.

Low-activation ferritic-martensitic steels have been developed with compositions tailored to reduce long-term-induced radioactivity by three to four orders of magnitude. Initial results indicate that these new alloys, based on 9 Cr-2W, V, Ta, have excellent resistance to radiation-induced loss of toughness. Neutron irradiation to ~7 dpa at 365°C resulted in an increase in DBTT of only ~4°C. Further irradiation experiments were recently completed in the Fast Flux Test Facility in which miniaturized impact specimens were irradiated to neutron doses of 14 and 22 dpa at 356°C.

The alloy, Incoloy 800H, was selected for several in-vessel components for the MHTGR. To assess the possible impact of helium generation on the mechanical behavior of weldments, an irradiation experiment was completed using the rabbit facility in the HFIR. Sheet tensile specimens of welds made with an Inconel 82 filler metal were irradiated at 400°C to a thermal fluence of 2.5×10^{24} n/m^2. In addition, an irradiation facility was designed for the outermost HFIR position, capable of running at 800°C. This position provides a good simulation of the environment of the MHTGR upper-core internals and will achieve an end-of-life fluence in about one year.

3.7 SUPERCONDUCTING MATERIALS – *D. M. Kroeger*

The Superconducting Materials Group does research on cuprate compounds which become superconducting at temperatures as high as 125 K. The goal of the studies is to develop practical conductors that can support large currents in high magnetic fields. The compounds studied can be divided into two main groups, those showing near-term promise for low-temperature applications and a second group which has good intrinsic current-carrying capabilities at higher temperatures and, thus, may be developed into practical liquid-nitrogen-cooled conductors. The Bi-Pb-Sr-Ca-Cu oxide "2223" phase is being developed for silver-clad conductors for use at temperatures below ~30 K. Examples of the second group of compounds include $YBa_2Cu_3O_{7-x}$(Y123), $Yba_2Cu_4O_8$ (Y124), and the Ti-Pb-Sr-Ca-Cu 1223 phase.

Synthesis of high-purity ceramic powders is emphasized, and aerosol pyrolysis of nitrate solutions is the route most frequently employed. Research samples have been produced by many techniques including sintering of cold-pressed pellets, deformation and annealing of silver-clad powders, liquid-phase processing, and high-pressure oxygen synthesis. A large variety of techniques are used to characterize the samples. Magnetic susceptibility, transport critical current density, magnetization, and electrical resistivity data are used to define superconducting properties. Microstructural characterization involves XRD, TEM, SEM, microprobe analysis, Auger spectroscopy, and optical microscopy.

Research on moderate-to-low-temperature conductors has been concentrated on using aerosol pyrolysis to produce powders for generating the 2223 Pb-Bi phase in silver-clad conductors. Portions of this work are performed in conjunction with industrial researchers and staff at the University of Wisconsin. The aerosol pyrolysis studies are being done in collaboration with the University of New Mexico.

Ceramic powders produced by aerosol pyrolysis have several advantageous properties, and the pyrolysis process has attracted industrial support. The advantages include precise compositional control, production of ultra-fine particles, and suitability for large-scale production. Problems associated with Pb loss and carbon contamination have been solved, and a 600°C vacuum heat treatment has been used to remove residual nitrates. Aerosol powders of Bi(Pb)2223 precursors have been used to prepare silver-clad superconducting 2223 wires and tapes. The times and temperatures required for processing of those aerosol powder precursors are typically less than those for precursors prepared by solid-state reaction. This may be due to the inherently fine scale of compositional homogeneity of aerosol powders and/or to a difference in chemical reaction paths for conversion of the aerosol and solid-state powders. These studies have also shown that the conversion of precursor powders to the 2223 phase is very sensitive to oxygen pressure, and optimum conditions have been defined. Deformation processing conditions also have a profound effect on conductor properties, and a substantial effort on this variable is being conducted by the Materials Processing Group.

Conductors containing Bi-Pb 2223 have excellent current-carrying capabilities when immersed in liquid He, but the J_C values fall off rapidly at temperatures above ~20 to 25 K. This is not the case for $YBa_2Cu_3O_{7-x}$, Y123 crystals. In this compound, the intragranular J_C values fall off much more slowly as the temperature is increased. Thin films of this compound have excellent J_C values but cannot carry significant amounts of current. Higher-current applications have been limited by slow growth rates observed for the formation from the melt and by "weak link" behavior associated with the GBs in sintered polycrystalline samples. Research on both of these limitations is being conducted in the Superconducting Materials Group.

Melt-processed Y123 samples exhibit high J_c values. These samples are produced by slowly cooling a two-phase mixture of Y_2BaCuO_3(211) and Y-poor liquid through the peritectic temperature, and TEM has been used to define the microstructure. Each domain consists of a single Y123 crystal containing finely dispersed 211 particles and planar defects. These defects lie in the ab plane, are not continuous, and contain amorphous material (which is probably the remnants of the liquid phase). Other liquid-phase processing methods yield similar microstructures. During this reporting period, research has been concentrated on evaluating the origin and consequences of this microstructure. These studies include an investigation of the growth mechanism, TEM work on the defects that form in the Y123 adjacent to the 211 particles, and a study of the mechanical properties of the Y123 crystallites.

Nucleation and growth of 123 from the melt via a peritectic reaction into domains of aligned platelets was studied in detail. Based on the microstructural analysis described above, a given domain is thought to grow from a single nucleus. It was also found that the platelet boundaries are filled in with secondary phases corresponding to the liquid phases at high temperatures, suggesting that constitutional supercooling effects may be operative. Samples quenched from temperatures considerably below the peritectic temperature during the cooling cycle indicated that there was a large nucleation barrier, and only a few 123 nuclei were present. The above observations, coupled with extensive microstructural examination of quenched solid-liquid interfaces, suggest that the 211 size, distribution, and volume fraction not only control the growth rate of 123 along the fast-growth ab plane (by the supply of yttrium), but also the growth rate along the slow-growth c-direction, since the nucleation barrier for growth is reduced at 211/123 intersections. A growth model consistent with these observations, which also explains the formation of 123 "domains," was proposed.

Flux-pinning in melt-processed Y123 has been observed to increase with the surface area of trapped 211 particles, thus providing an opportunity to identify flux-pinning structures. TEM and EDS were used to study the 123 microstructure near the 211/123 interface. It was found that near the 211/123 interfaces, there is a high local density of stacking faults in the 123. The stacking faults lie parallel to the (001) basal plane and are inhomogeneously distributed around the 211 particles. They tend to be disk shaped with diameters ranging from a few to ~30 nm. Calculations made using simple energy considerations suggest that these stacking faults may act as effective flux-pinners for magnetic fields directed both parallel and perpendicular to the basal plane. They may account for the observed increase of J_c with volume fraction of 211 and also explain the angular dependence of transport J_c in melt-processed 123.

The microhardness, Young's modulus, and fracture toughness of aligned 123 obtained by melt-processing were found to be highly anisotropic. Microindentation measurements showed that the (100) planes are the preferred fracture planes in this material and that the critical stress-intensity factor for propagating a crack on the (001) basal plane is the lowest, i.e., $K_c(001) < K_c(100)$ or $K_c(010)$. Indentation crack length measurements on the (001) basal plane with the impression diagonals aligned parallel and perpendicular to the [100] and [010] directions indicate that the fracture toughness of these planes is K^{air} (100/010) = 0.8 $MPam^{1/2}$. The microhardness in this orientation was found to be 6.7 GPa. Measurements on a plane perpendicular to the basal plane resulted in a lower hardness of ~3.8 GPa. This reduction in hardness is influenced by the extensive preferential cleavage of the (001) basal planes.

The Young's modulus was determined using a highly spatially resolved MPM. Nanoindentation measurements on the (001) cleavage plane of aligned 123 indicated a Young's modulus of 143 ± 4 GPa. For measurements on a plane perpendicular to the cleavage plane, a value of 182 ± 4 GPa for the modulus was obtained. A lower modulus in the c-direction is perhaps a result of the layer-like structure of 123, resulting in weak coupling between the layers. Measurements on the trapped single crystalline 211 particles resulted in a Young's modulus of 213 ± 5 GPa. Considerations of the thermal and elastic mismatch effects between the trapped 211 particles and the 123 matrix, the large thermal anisotropy of aligned 123, and microstructural examination of polished and fracture surfaces of aligned samples indicate that the 211 particles serve to enhance the fracture behavior of 123 by energy dissipation due to interfacial delamination and crack bridging.

Silver-clad conductors containing $Tl_{0.5}Pb_{0.5}Sr_{1.9}Ca_{2.1}Cu_3O_x$(1223) have shown some promise for liquid-nitrogen-cooled applications, and a study of this system has been initiated. Powders were produced by aerosol pyrolysis, encapsulated in silver, and cold drawn. Post-deformation heat treatments produced samples with onset temperatures of 110 to 120 K, but XRD data showed that they were not phase pure. Future work will focus toward understanding phase formation, the effects of starting composition and phase assemblage, and the microstructure of these tapes.

There are three superconducting Y-Ba-Cu-O compounds; $YBa_2Cu_4O_8$(Y124), which has a T_c of 80 K, also has intrinsic J_c values comparable to Y123. The potential of this compound as a conductor material has been evaluated by the Superconducting Materials Group. Dense, phase-pure samples were required for the experiments, and phase stability data were obtained while investigating various synthesis routes. High-pressure oxygen environments do not decompose Y124, and the range of stability of the phase is larger than has been reported in the literature. An explanation for the enhanced stability has been developed, and good quality research samples were produced by sintering at 1030°C in 83 atm O_2. These conditions are within 5° of the liquid-formation temperature at this pressure.

These samples were used to study the relationship between weak link behavior and GB chemistry. Previous work had shown that the compositions of Y123 GBs, which are weak links, differ significantly from bulk values. For Y124, both Auger spectroscopy and TEM microanalysis show that the GB compositions are indistinguishable from values for the bulk. Susceptibility data obtained in weak magnetic fields demonstrate that the stoichiometric Y124 GBs are also weak links. These observations demonstrate that weak link behavior can be an intrinsic effect.

An apparatus for thermal conductivity studies has been constructed and tested. A National Bureau of Standards stainless steel thermal conductivity standard was used for the tests, and over the 6 to 300 K operating range, the results have an average uncertainty of -2.2%. A series of polycrystalline Y124 samples is now being studied. Preliminary results show that the thermal conductivity curves for this compound differ significantly from the data for Y123. Electrical conductivity curves for the two compounds also show large differences. The goal of this research is to produce data that will aid in understanding the basic mechanism of superconductivity in high-T_c compounds.

3.8 IRRADIATED MATERIALS EXAMINATION AND TESTING – *L. J. Turner*

The primary mission of the group is to provide support for the postirradiation examination (PIE) effort for structural materials research conducted by several groups within the M&C Division. As such, the group is responsible for operation and maintenance of the Irradiated Materials Examination and Testing Facility in Building 3025E. Funding is provided from several sources; among these are the MFE Program, the SNP (SP-100 Project), the HSSI Program of the USNRC, the NPR-MHTGR Program, the BES Program, and several smaller WFO Programs. During this reporting period, most of our experimental work involved support for the Structural Materials and Defect Mechanisms Groups of the Materials Science and the Fracture Mechanics and Mechanical Properties Groups of the Engineering Materials Section.

Work for the Structural Materials Group was primarily in support of the MFE Program. During this period, TEM disks were prepared for density measurements on ferritic and austenitic developmental alloys from the HFIR-MFE-JP-10 experiment. Tensile testing of FWB structural developmental alloy candidates for the U.S./Japan collaborative testing program was completed on specimens from the ORR-MFE-6J and -7J, two spectrally tailored experiments. Tensile tests were completed for the remaining specimens from HFIR experiments CTR 39, 40, and 41. SEM of the fracture surfaces of tested one-third-size CVN specimens from the Materials Open Test Assembly (MOTA) 1E low-activation experiment and tensile specimens from HFIR CRT-50 and ORR-MFE-6J and -7J were conducted in cell 1. Charpy impact testing and SEM of one-half CVN specimens from the HFIR CTR-53 and -54 experiments were completed for the MFE Program. Leak detection tests were completed on pressurized tubes from ORR-MFE-6J and -7J in preparation for reassembly in HFIR-MFE-200J-1 and 400J-1. Preliminary experimental techniques were developed and proved, and testing began on controls of miniaturized compact tension specimens in preparation for testing neutron-irradiated specimens irradiated in HFIR experiments HFIR-MFE-JP-18 and -19. During September and part of October 1992, two reactor experiments, HFIR-MFE-200J-1 and HFIR-MFE-400J-1, consisting of both cold- and previously neutron-irradiated specimens, were assembled in cell 6.

Tensile tests were conducted in cell 2 in support of several radiation-softening experiments conducted for the BES Program on aluminum alloys used for structural components in the HFIR core assembly. Tensile testing was also completed for several experiments designed to study the radiation embrittlement of ferritic steels. This work began as a dedicated study of the embrittlement of the HFIR pressure vessel and has since expanded to include studies of LWR pressure vessels as well.

Tensile testing was completed for the Mechanical Properties Group on approximately 40 high-temperature Rhenium specimens for the DOE SNP Program, SP-100 Project.

Work for the Fracture Mechanics Group dealt predominantly with support for the HSSI Program of the USNRC, the NPR-MHTGR Structural Materials Program, and the ANS Project. During this reporting period, tensile testing was started on specimens from capsules 5 and 7 of experiment FNR-3 units A and B. This work will continue into FY 1993. The crack starter holes were enlarged and testing completed on the last 20 crack-arrest duplex specimens from the HSSI Sixth Series Phase II experiment. Sixteen 0.45-T compact tension and 15 SS-3 tensile specimens from the ANS experiment HANSAL-T1 were disassembled and tested in cells 2 and 3.

In July 1992, facility cell work was temporarily halted until an evaluation of the effectiveness of the basic shielding envelope could be determined. This effort required many person-hours and resulted in an extensive study for this facility due, in part, to the absence of background information on the subject and the age of the facility. Each cell was assessed on an individual basis using a phased approach. As corrective actions were completed, each cell was returned to service in accordance with ORNL procedures. The effort was completed for the final cell on November 30, 1992.

With regard to personnel, the group realized an overall growth this year. During the year, one chemical operator retired and two others were hired. In February 1992, a Principal Technologist joined the group to perform mechanical testing and assist the Facility Manager with the development of new test equipment.

A great deal of work behind the scenes was required to accomplish the materials testing we completed this year. To achieve these goals, 170 cask moves, 32 cell entries, completion of 118 radiation and 29 safety work permits, 506 in-cell tensile, 84 Charpy impact, 15 crack-arrest, 33 compact tension, and 37 SEM analyses were required.

3.9 RESEARCH SUPPORT GROUP – *A. T. Fisher*

The Research Support Group prepares alloy and ceramic specimens for TEM, AEM, APFIM, and related analyses. This year the group's work has expanded to include specimen preparation of polymers as well as metals (such as iridium, iron aluminides, nickel aluminides, and superconductors) and ceramics (such as magnesium oxide and alumina). Assistance and instruction were provided for SHaRE participants, university students, and foreign visitors. The Research Support Group provided specimen preparation for one of the first collaborations with Russia on fusion materials.

A new technique was developed to prepare Ni_3Al particles for atom probe examination by embedding the particles in nickel plating. General maintenance was provided for electron microscopes and APFIM facilities. Assistance was provided for the continuing assembly of two atom probe instruments. A bibliography of atom probe-related publications for 1990 was published, and a bibliography for 1991 was compiled. A work station and equipment were acquired for the preparation of radioactive atom probe samples. Personnel were trained and certified in the handling of radioactive materials.

This past year the group prepared 1291 samples for TEM/AEM analysis and 298 specimens for APFIM. Ceramic specimens prepared by ion milling numbered 180. Photographic support for the Radiation Effect and Microanalysis Group consisted of 325 photographic work orders comprising 13,400 prints.

4. CERAMIC SCIENCE AND TECHNOLOGY

R. L. Beatty

Research in the Ceramic Science and Technology Section focuses on (1) the development of strong, tough ceramic matrix composites; (2) the characterization of carbon, graphite, and coal for nuclear, space power, and other applications; (3) the understanding and development of supporting processing technologies; and (4) the evaluation and development of advanced thermal insulation systems. Consisting of approximately 35 professional and 20 technical support personnel, the section is organized into five groups: Carbon Materials Technology (CMT), Ceramic Processing, Ceramic Surface Systems, Structural Ceramics, and Materials Thermal Analyses (formerly Building Materials).

4.1 CARBON MATERIALS TECHNOLOGY — *T. D. Burchell, E. L. Fuller, O. C. Kopp, D. F. Pedraza, J M Robbins, G. R. Romanoski, L. L. Snead, J. P. Strizak, and C. E. Weaver*

During this reporting period, the majority of the CMT Group's activities were associated with the NPR-MHTGR Program. Other R&D tasks included the Fusion Energy Carbon-Carbon (C/C) Composites Program, the Graphite Impact Shell (GIS) Materials Improvement Program, the CFCC Production Maintenance and Product Improvement Program, the Commercial MHTGR Program, and Coal Characterization Studies. These activities were supported by the Illinois State Geological Survey; the ONPR; the Office of Fusion Energy; the RTG Program, Office of Special Applications; the Office of Advanced Reactors; and U.S. DOE. Summaries of the CMT Group's activities in this reporting period are given below.

4.1.1 Fusion Energy Carbon Materials

Research activities for fusion energy application have been in support of plasma interactive or high-heat-flux materials needs. Graphite and C/C composite materials are selected for these applications because their low atomic number minimizes radiative heat losses from the plasma. Plasma-facing materials (PFMs) requirements include extremely good resistance to thermal shock, erosion, and neutron damage.

Fusion energy carbon studies are focused in two major areas: experimental determination of the effects of neutron damage on candidate PFMs and fundamental studies of irradiation-induced crystal-structure damage in carbons. PIE of specimens from two HFIR irradiation experiments, HTFC I and II, was undertaken. These two capsules were irradiated at 600°C to peak damage levels of 1.6 and 4.7 dpa, respectively. The experiments contained a variety of carbon materials including: nuclear-grade graphite (H–451); one-, two-, and three-directional C/C composites; and a random fiber C/C composite. In this period, specimen PIE was concentrated on thermal conductivity determinations.

For two 3-D C/C composite materials, thermal conductivity was shown to reduce by ~60% on irradiation at 600°C to neutron damage doses >1 dpa. The conductivity at 600°C was observed to saturate at ~1 dpa and remained constant at doses up to ~5 dpa. The fractional reduction of thermal conductivity was greater at room temperature than at the irradiation temperature. Thermal annealing to 1600°C, after irradiation, restored the thermal conductivity to ~80% of its unirradiated value. The results of our work were presented at the 5th International Conference on Fusion Reactor Materials, Clearwater, Florida; the ASTM Symposia on Radiation Effects in Materials, Denver, Colorado; and the International Conference on Carbon, Essen, Germany. Moreover, our results were summarized and presented at the U.S./Japan Workshop on High-Heat-Flux Component in Kyushu, Japan. Two open-literature publications on this work have been published in this reporting period, one in the *Journal of Nuclear Materials* and the other in ASTM STP 1175.

Fundamental studies of radiation damage in graphite have continued. A study using electron irradiation showed that at fluences up to 1.1×10^{27} e/m^2, graphite remained crystalline. HREM and selected area diffraction patterns indicated that ordering along the c-axis remained. The energy required to displace a carbon atom from the lattice, E_d, was determined to be 30 eV, in agreement with previous studies. However, no angular dependence of E_d was detected. Other studies have utilized 35-KeV C ions to damage carbon specimens. Raman spectroscopy of the damaged carbon revealed details of the nature of irradiation-induced microstructural changes. The effects of annealing were investigated. Mathematical modeling of the irradiation process has continued. Point defect energetics and diffusion mechanisms in graphite were investigated using a semi-empirical, tight-binding force model, and possible diffusion processes associated with point defect (i.e., vacancies and interstitials) and non-defect (i.e., atomic exchange) mechanisms were analyzed. It was postulated that self-diffusion in graphite in a direction parallel to the basal plane could be mediated by vacancies. However, since the calculated vacancy and interstitial formation energies are nearly equal, it can be argued that Frenkel pairs could exist as equilibrium defects. In this case, at high enough temperatures, self-diffusion parallel to the basal plane should occur by an interstitial mechanism because the migration energy of the interstitial is much lower.

In the past year, U.S. research activities for fusion energy have been focused on the design of the ITER. The PFM for this reactor will see as high as 20 MW/m^2 in ion flux as well as appreciable neutron flux. The primary candidate materials considered as the PFM for ITER are C/C composites. Toward this end, research into the degradation in the conductivity of high-conductivity ($K > 500$ W/m-K) graphite composites has begun. Thermophysical property determinations of C/C composites, neutron irradiated up to 1200°C, are being planned in the HTFC-3 capsule. The two previous HTFC capsules investigated the effect of irradiation on various C/C composite architectures and fiber types at a lower temperature.

As the ITER Program combines the research programs from the United States, European Community, Japan, and Russia, an effort has been made to coordinate research among the ITER partners for the PFM irradiation program. Specific collaborations have begun in the areas of thermal conductivity degradation of graphite and the braze integrity of C/C composites to copper following irradiation. Detailed planning and design commenced for a HFIR in situ capsule for thermal conductivity degradation studies of high-conductivity composites.

4.1.2 Commercial MHTGR Program

Activities during this reporting period have been in support of the U.S. DOE's international agreements on gas-cooled reactor (GCR) development with the JAERI and with Germany. U.S./Japan collaborative activities have centered on two areas: (1) PIE of HFIR irradiation capsule HTK-7, specimens of U.S., Japanese, and German nuclear graphites; and (2) specimen volume effects on the strength and fracture toughness of U.S. and Japanese nuclear-grade graphites.

A study of the effect of specimen size on the brittle ring strength of IG-110 graphite was started. Several hundred specimens of varying volumes were designed and machined. PIE of graphite specimens from HFIR target capsule HTK-7 was conducted in this reporting period. Data for dimensional and volume changes, strength and elastic moduli changes, and thermal-physical properties were taken. A preliminary letter report of the PIE data was prepared. During March and April 1992, a staff member from the JAERI's Materials Strength Laboratory was assigned to the CMT Group and assisted in the PIE of specimens of IG-110 graphite.

One subprogram management meeting was held under the U.S. DOE-German umbrella agreement. Activities under this agreement are related to the PIE of German graphites irradiated in HFIR capsule HTK-7 and the analysis of H-451 creep data obtained from irradiation in the High Flux Reactor, Petten, The Netherlands.

4.1.3 New Production Reactor MHTGR

A wide range of technology development activities were ongoing through this reporting period in support of the NPR-MHTGR Program. These included: thermal, mechanical, fracture, and fatigue data base development activities for grade H-451 graphite; air oxidation studies of grade H-451 graphite; examination of candidate cokes for the production of H-451, including irradiation of pilot-scale developmental H-451 graphites; an alternate graphite vendor program; and a C/C composite control rod materials development program.

4.1.3.1 Thermal properties

A comprehensive test plan describing the approach, methods, techniques, and apparatus to be used in generating the NPR-MHTGR graphite thermophysical properties data base was approved. The plan gives details of the test matrix, materials, cutting diagrams, and specimen configurations to be used. In accordance with our approved test plans, a graphite billet was cut up and 768 specimens machined from a 2-in.-thick center slab for evaluation of the spatial variation of thermal properties. Test measurements commenced following a successful readiness review. Data taken in this reporting period included spatial variability of thermal conductivity, variation of thermal conductivity with specimen orientation, and temperature.

A model for the thermal conductivity of graphite was developed in collaboration with Professor P. Klemens, University of Connecticut. Graphite is modelled as a series of links and junctions, the former representing the crystallites and the latter the intercrystallite regions. This model allows the estimation of the effect of conductivity of polycrystalline graphite from a knowledge of the principal conductivity ratio; the conductivity along the basal planes; the microstructural features (crystallite size and shape, number, and geometry of intercrystallite contacts per crystallite); and the density. Application to nuclear-grade graphites gave satisfactory agreement with experimentally measured thermal conductivities.

4.1.3.2 Mechanical properties

Work during this reporting period was focused on the preparation and approval of detailed test plans and machining of approximately 1,500 tensile test specimens. The specimens were taken from large billets of H-451 graphite, one billet of each of four strength classifications for one particular manufacturing lot, and one billet of class 1 material from two additional lots. Testing commenced to determine the effects of spatial variability and specimen orientation within a billet, class-to-class variability, and lot-to-lot variability on tensile strength.

4.1.3.3 Fracture mechanics

The plane-strain chevron-notched fracture toughness test method (ASTM E 1304-89) has been employed to measure fracture toughness of several grades of nuclear graphites including: Great Lakes Carbon grade H-451, Stackpole grade 2020, and Toyo Tanso grade IG-110. Specimen size effects were investigated using the chevron-notched, short-rod (CNSR) specimen geometry. Preliminary results have been reported for the graphites. Fracture toughness was found to increase with increasing specimen size. This behavior was attributed to a rising "R-curve" behavior for these graphites. The small volume requirements of the CNSR specimen allowed for a localized measure of fracture toughness, permitting an evaluation of the effects of spatial location and orientation within a fuel element graphite billet. The CNSR specimen is compatible with the specimen size limitations of HFIR irradiation capsules. Fracture mechanics data are needed for the design of the MHTGR.

4.1.3.4 Fatigue behavior

During the previous reporting period, a specimen geometry and test procedure were developed for fully reversed, load-controlled fatigue testing of nuclear graphites. During the current reporting period, detailed test plans were developed and approved. Approximately 1000 fatigue specimens were machined from four large billets from one lot of H-451 graphite, one billet of each of four strength classifications. Testing commenced to determine the effects of spatial variability and specimen orientation within a billet, and class-to-class variability on fatigue behavior.

4.1.3.5 Oxidation studies

The kinetics and mechanisms of the reaction of air with graphite have been evaluated over a wide range of temperature and humidity for Great Lakes Carbon grade H-451 and Toyo Tanso grade IG-110. The interpretations of the data were supplemented by additional microscopic and chemical analyses. Density profiles were evaluated for varying degrees of reaction to show that the corrosion processes proceed by pitting and etching of the outer regions of the substrate. Trace amounts of silica seem to inhibit the pitting process and retard oxidation appreciably. Corrosion by water vapor (in helium carrier gas) proceeds by a similar mechanism, albeit much more slowly at given temperatures (400 to 1600°C).

4.1.3.6 Coke source examination

Three HFIR irradiation capsules were dedicated to an investigation of the influence of precursor isotropic petroleum coke on graphite properties and response to irradiation temperature and fluence. This investigation continued throughout this reporting period. The first of the three capsules, HTN-1, was reported in the last reporting period. During this report period, PIE was completed and a report was issued.[1] These data indicated a significant difference between the graphites. Two of the pilot plant candidate graphites showed promise as replacements for original H-451, namely the so-called D- and G-coke graphites. However, it is not possible at this point to make firm recommendations regarding coke type selection. Further data are required from experiments HTN-2 and -3 prior to making a final selection of replacement cokes.

The other two capsules, HTN-2 and -3, were irradiated at 600 and 900°C, respectively. The capsules contained duplicate specimens of graphites manufactured using various cokes. These capsules have completed their irradiation cycles and have been removed from the HFIR. They are being held in the cooling pond until arrangements are completed to move them to the hot cells for disassembly. This is anticipated to happen sometime in January 1993.

4.1.3.7 Alternate vendors program

Two irradiation capsules, HTN-4 and -5, are being prepared at the request of DOE ONPR to evaluate nuclear-grade graphites from alternate vendors for possible replacement of H-451 for the NPR-MHTGR. HTN-4 and -5 were designed as HFIR capsules to operate at 900 and 600°C, respectively. The capsules duplicate in design HTN-2 (600°C) and HTN-3 (900°C), except that HTN-4 has been modified to accept a 7-TC array tube with graphite tubes replacing the graphite splines centering the specimens.

Seven grades of graphites from four different vendors were selected for irradiation in HTN-4 and -5. Those selected were three grades from UCAR Carbon Company, Inc., one from POCO Graphite, Inc., two from Great Lakes Carbon Company, and one from the Carbon/Graphite Group. Specimens for these two capsules were machined, and dimensional measurements were essentially completed in this reporting period. The specimens are presently undergoing preirradiation property evaluation. When these characterization measurements are completed, the specimens will be made available for

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[1]T. D. Burchell, J M Robbins, and J. P. Strizak, *Assessment of Post Irradiation Examination Data From HFIR Capsule HTN-1*, ORNL/NPR-91/35, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., December 1991.

assembly into capsules or will be labeled, packaged, and stored for future use. In light of the announcement to end the ORNL NPR-MHTGR Program, it is anticipated that the specimens will be stored for future use.

4.1.3.8 C/C composite control rods

A technical plan for the development of C/C composite materials for high-temperature NPR-MHTGR control rods was written. The plan described the strategy and technology program for control rod material development, including arguments for the selection of fiber, matrix, and processing details. Design drawings and a purchase specification were appended. An order for braided composite control rod tubes, 3-D C/C couplings, and one-dimensional C/C clevis pins was placed with Fiber Materials, Inc., Biddeford, Maine. Control rod component testing will commence in the next reporting period.

4.1.3.9 NPR-MHTGR fuel compact thermal conductivity

Fuel compacts containing 10 and 20 vol % of eight-layer TRISO [TRI-material (buffer, silicon carbide, pyrolytic carbon) ISOtropic coatings] fuel were sectioned to yield thermal conductivity and specific heat specimens. Thermal diffusivity was determined using our LASER flash thermal-pulse measurement system at temperatures up to 1600°C. Similarly, the specific heat was determined at temperatures up to 1000°C. The thermal conductivity of the fuel compacts was calculated and found to be significantly less for the 20 vol % compact compared to the 10 vol % compact. Our data indicated that the NPR fuel compacts had lower thermal conductivities than five-layer fuel-containing compacts prepared previously for the commercial MHTGR Program. The reduction in conductivity was attributed to the significantly lower carbonization temperatures now employed during fuel compact manufacture.

4.1.4 Improved GIS

The GPHS provides power for space missions by transmitting the heat of ^{238}Pu decay to thermoelectric elements. Because of the possibility of an aborted mission, the heat source must be designed and constructed to survive both reentry heating and earth impact. Cylindrical GIS contain the iridium alloy-clad fuel pellets and serve a principal role in impact protection. The present GIS configuration is machined from an orthogonal-weave C/C composite and is susceptible to longitudinal fracture during impact. Cylindrical-architecture C/C composites are being evaluated as a potential improvement to GIS impact performance. Characterization includes measurement of physical, thermophysical, and mechanical properties.

A gas gun test facility is being prepared for impact testing of candidate GIS materials to evaluate the effect of architecture and density on energy absorption. Impact tests will be conducted at room temperature using one nickel-clad hafnia fuel simulant in a half-length GIS specimen. Each GIS specimen plus fuel simulant will be fired at 55 m/s (reentry terminal velocity) into an instrumented steel target that produces an output proportional to the deceleration of the projectile. A GIS material that yields a lower deceleration rate will provide greater protection to the PuO_2 fuel under simulated impact conditions.

4.1.5 Carbon-Bonded Carbon-Fiber Insulator Material

Lightweight thermal insulating material is required in the GPHS for space reactors used to provide power for NASA's deep space probes. Carbon-bonded carbon-fiber (CBCF) thermal insulators fabricated for the RTG Program are presently used to fulfill this function. Schedules were met for production and documentation of 40 flight-quality sets of CBCF parts in support of the NASA Cassini mission. Parts produced earlier are currently flying in the Galileo and Ulysses spacecrafts. As the production schedule for the Cassini mission was completed, emphasis shifted to more complete characterization and improvement of CBCF insulating materials. Additional material has been produced and density mapping studies initiated to provide a more extensive material property data base.

4.1.6 Chemistry and Structure of Coals

Chemistry and structure of a set of Illinois Basin coals have been studied in a cooperative program with the Illinois Geological Survey. Comminution to finer sizes (i.e., 100 to 400 mesh) is accompanied by chemical changes. The hydroxyl content (alcoholic, phenolic, acidic functional group and/or bound water) is diminished, and the aliphatic hydrocarbon content is enhanced. The diffuse reflectance infrared spectroscopy (DRIS) technique is ideally suited for evaluating the effect of the added energy input required to decrease the coal particle size.

Temperature-programmed reaction studies of air reaction with coals of various ranks [the Argonne National Laboratory (ANL) Premium Coal Sample Suite] have been used to evaluate oxidation and gasification mechanisms. Mass spectroscopic analyses of the effluent gases reveal that the initial mass loss is due to aliphatic hydrocarbon evolution. Oxidation occurs at higher temperatures as recognized by carbon dioxide, carbon monoxide, and water vapor in the effluent vapors. Detailed DRIS examinations of eight different samples before and after exposure to ambient conditions at room temperature for one month revealed no noticeable chemical or structural change (either at 400 or 100 mesh). The oxidation processes proceed at such a slow rate that the changes are undetectable. Previous DRIS studies have been used to obtain details of the oxidation processes at higher temperatures.

4.2 CERAMIC PROCESSING — *A. E. Pasto, M. A. Janney, J. O. Kiggans, H. D. Kimrey, R. J. Lauf, A. J. Moorhead, O. O. Omatete, S. D. Nunn, and T. N. Tiegs*

Group R&D activities include ceramic forming by gelcasting, microwave processing, in situ-toughened silicon nitride materials development, high-temperature corrosion, material characterization, and sensor development. These activities are supported by the CTAHE Program, Office of Transportation Systems; the AIC and Advanced Industrial Heat Exchanger Programs, Office of Industrial Technologies; the Fossil Energy AR&TD Materials Program, Office of Technical Coordination; the RTG Program, Office of Special Applications; the ONPR; and the Office of Energy Research, U.S. DOE.

Ceramic gelcasting is being developed as a net-shape-forming method that may offer both manufacturing advantages and improved reliability of products compared with forming by slip casting or injection molding. The gelcasting process disperses ceramic powder in an aqueous solution of monomer, and "gelling" is accomplished by thermal polymerization. As reported during the last several years, initial, very successful studies were conducted using alumina powder and acrylamide monomer. The gelcasting process was then extended to silicon nitride, and several powders and compositions were successfully processed.

The gelcasting process has generated considerable interest in the commercial ceramic processing industry. We currently have in place a CRADA with the Garrett Ceramic Components (GCC) Division of Allied-Signal Aerospace Corporation and a CRADA with Coors Ceramics Company. In addition, we are evaluating the process using the materials of a number of potential licensees who would like to use gelcasting in the production of their products.

Under the CRADA with GCC, it was previously demonstrated that a silicon nitride T-25 turbocharger rotor could be formed by the gelcasting method using Garrett's proprietary GN-10 silicon nitride composition. In continuing work under the CRADA during the present reporting period, it has been shown that the gelcast GN-10 silicon nitride has virtually the same mechanical properties as the slip-cast material, which was Garrett's previous preferred forming method.

Cooperative work between ORNL and Coors Technical Ceramics has continued in which complex shapes utilizing Coors-supplied alumina powders were gelcast. This resulted in the implementation of a CRADA with Coors. ORNL is to gelcast and dry-prototype perforated discs using a mold provided by Coors. Coors will fire the discs, and both Coors and the end user will evaluate the finished product.

Five other companies have shown interest in the gelcasting process. Preliminary fabrication tests were conducted on materials of particular interest for each.

Fabrication of numerous ceramic materials by gelcasting has shown the process to be very versatile and attractive for complex shapes and potentially for large parts. However, the acrylamide monomer used for most of the development work has a toxicity level that renders it undesirable or unacceptable for scaled-up manufacturing application. Thus, an important part of the work has been a search for alternative monomers to replace the neurotoxic acrylamide. Extensive development work has been carried out on two systems, methacrylamide-poyethylene glycol (MAM-PEG) and methacrylamide-methylenebisacrylamide (MAM-MBAM), to replace the acrylamide system in the aqueous gelcasting process. Slurries of ceramic powders in the systems were prepared, and high-solids loadings were obtained. Subsequently, both systems have been successfully used to fabricate alumina and silicon nitride parts. In addition, the systems have been used to fabricate parts from other ceramic powders, such as silicon carbide and mixed oxides, provided by companies interested in the gelcasting process. Most of the current work in gelcasting is now carried out in either of the new systems, although comparative studies still involve acrylamide.

In addition to chemistry changes, the methods used for mixing the ceramic powder in the monomer solution have been changed to improve dispersion, particularly in the case of fine-particle-size silicon nitride and alumina powders. This results in a more castable slurry and higher quality parts that show substantially improved mechanical properties. New casting methods are also being examined to minimize mold-filling defects when forming complex shapes.

A project entitled "Novel Near-Net-Shape Processing of Engineered Ceramics" has been initiated, which is funded by the NIST, Advanced Technology Program. In this project, ORNL is contracted by GCC to develop gelcasting as a general ceramic manufacturing process. The project is broken into four major tasks: development of new gel systems, integrated processing development of ceramic slurry and gelation system, optimization of gelcasting system, and determination of product feasibility and process repeatability. This work is scheduled to take three years.

Ceramic processing and material characterization support is being provided to the Cost-Effective Machining of Ceramics Project in the development of a computer model for describing and analyzing an alumina tape-forming process for the production of electronic substrates. This work is part of a CRADA with Coors Ceramics Company to better understand ceramic processing as we move toward near-net-shape forming to minimize the amount of machining that is required to produce a finished part. Microwave processing development was continued with several ceramic materials.

In work for the FEMP, it was demonstrated that the "microwave effect" in the sintering of zirconia (lower sintering temperature during microwave heating) is a function of the type of dopant used in the zirconia. A previous study had shown a "microwave effect" of about 100° C for the sintering of ZrO_2 - 8 mol % Y_2O_3 at 2.45 GHz. The current study showed only a 50° C "microwave effect" for the sintering of ZrO_2-12 mol % CeO_2. The smaller effect for the CeO_2-doped zirconia is attributed to the lower ionic conductivity of that material relative to the Y_2O_3-doped zirconia. Similar effects have recently been observed for ion exchange in glasses by a group at the University of Florida; the higher the ionic conductivity of the glass, the larger the "microwave effect."

Work on the AIC Program focused on two areas: developing methods for microwave firing zirconia-toughened alumina (ZTA) composites at 2.45 GHz without auxiliary heating and developing a computer model to predict the heating behavior of ceramics in a microwave furnace. Previous work on microwave sintering of ZTA depended on the use of a "picket fence" arrangement of SiC rods to aid in heating the samples to temperatures above 600° C, where the zirconia and alumina will couple on their own. This is a cumbersome approach, which although useful for laboratory experiments, is unacceptable for production. An alternative method was developed that used carbon black as an internal auxiliary heater. The carbon was admixed with the alumina and zirconia during the mixing stage of sample preparation. At low temperatures, the carbon couples well with the microwaves to provide good energy transfer to the part. At about 500° C, the carbon burns off and the zirconia starts to heat on its own to raise the sample to the sintering temperature. Samples heated in this fashion exhibit a "microwave effect" that is comparable with that observed for samples heated using the picket fence.

Under AIC Program funding, a collaborative effort with the University of Utah continued, developing numerical models for microwave sintering of ceramics. Techniques were developed using finite-difference time-domain (FDTD) algorithms which demonstrate for the first time the heating process in a realistic microwave furnace. Efforts were initiated to develop engineering models for the microwave process, which will be useful for commercializing this process.

Internally, a quasi-optical model (an approximate model that is useful for detailing overall conditions in a microwave furnace) was developed that can be run on a Macintosh computer in a fraction of the time required for the FDTD codes. Using dielectric properties of the materials involved, the code can predict, surprisingly accurately, where the microwave power will be deposited.

An alumina test system was chosen for study both experimentally and using the quasi-optical model. The test sample was a sintered 400-g block of high-purity alumina. It was insulated with 1.5 in. (4 cm) of high-purity alumina fiberboard. Forward and reflected power in the cavity was measured. The power diagnostics were calibrated calorimetrically. Excellent agreement was obtained between the experimental results and the model predictions, which indicates the usefulness of the model in predicting the behavior of systems during microwave heating. Microwave efforts were also sponsored by DOE-DP.

A three-year effort to develop a world-class microwave furnace was completed this year. The advanced manufacturing process furnace is a dual-frequency, controlled-atmosphere microwave furnace. It has 48 kW of 2.45 GHz power and 15 kW of 28 GHz power. It is capable of operating in inert, oxidizing, or high-vacuum (1×10^{-7} pascal) conditions.

Other work sponsored by ER included the initiation and approval of a CRADA with Dow Chemical Company to demonstrate the feasibility of microwave processing of silicon carbide ceramics. The CRADA will run for three years. Techniques will be developed to sinter SiC in the microwave and compare results in a conventional furnace.

The primary microwave processing work for the CTAHE Program has been the study of microwave heating as an alternative for producing cost-effective sintered reaction-bonded silicon nitride (SRBSN) materials. Previous studies indicate that it offers several advantages over conventional heating of similar materials. These are: (1) nitridation initiates at a slightly lower temperature (50°C), (2) nitridation occurs at a faster rate, (3) densification rates are increased, (4) nitridation and sintering are done in one continuous process, (5) thicker parts can be made because nitridation proceeds from the inside out and pore closure is minimized, and (6) cooling of the parts can be performed outside the microwave cavity because the insulation is not an integral part of the furnace. Consequently, microwave heating offers a way to reduce fabrication times and handling time of components. It is also significant that SRBSN materials cost about one-fourth the amount of expensive silicon nitride powders. Significant progress has been made in this project. Data have been published showing that microwave sintering of several SRBSN materials was more effective than conventional sintering. Mechanical testing was conducted on several of these SRBSN materials, showing that the room-temperature strength is comparable to materials made by other processes. However, flexural testing at elevated temperatures showed appreciable strength decrease at temperatures above 1000°C. The fracture toughness values ranged from 4.5 to 5.1 $MPa\sqrt{m}$ for the SRBSN materials tested to date. This is lower than values obtained for samples prepared from high-purity Si_3N_4 powders, which are in the range of 6.8 to 7.0 MPa$\sqrt{m}$. Work is progressing in microwave processing of complex parts of SRBSN and in scaling up the total volume of parts processed per run. Also, modifications are soon to be made to increase the uniformity of our microwave furnace.

Work on the three microwave CRADAs with Norton and Allied Signal is nearing completion. Samples have been provided to us by the participants, and all of the samples have been processed by various microwave heating schedules. New packaging techniques, which were developed just prior to the start of these CRADAs, greatly increased the uniformity of heating and enabled us to successfully process most of the samples. XRD, SEM analysis, and mechanical testing of the processed samples are being conducted. Early results indicate that microwave annealing improved the high-temperature properties of dense Si_3N_4 provided by Norton. Follow-up runs have been made to further study the process. In the RBSN material provided by Norton, microwave processing produces a much finer pore size than for materials processed by conventional heating.

Two additional CRADAs on microwave work were initiated last year under ER Programs. One is with AVX Tantalum Corporation to evaluate microwave sintering of tantalum capacitors, and the other is with Microwave Laboratories, Incorporated (MLI) to develop a variable-frequency furnace.

MLI has licensed the variable-frequency furnace and has developed a broad line of products ranging from a 200-W benchtop unit to large, multikilowatt systems and has demonstrated very exciting results in materials processing applications.

Also, working with AVX Tantalum, we have observed several potentially exciting phenomena in microwave-processed Ta capacitor anodes. These unique products are the subject of a U.S. patent application entitled "Process for Manufacturing Tantalum Capacitors" and are currently being evaluated at AVX Tantalum.

Non-microwave work sponsored by the CTAHE Program is directed toward in situ-toughened (or self-reinforced) silicon nitride. Toughening is achieved by the development of elongated-grain microstructures that have carefully controlled intergranular phases to promote crack deflection, debonding, bridging, and pull-out.

A series of compositions was prepared using two refractory sintering aid compounds: rare earth apatites and rare earth silicates. Four different rare earth cations were examined: Y, La, Nd, and Yb. Gas-pressure sintering at temperatures up to 2000°C was used to densify these compositions while developing a highly elongated (acicular) grain structure. A two-step firing schedule was used to promote the formation of a bimodal grain-size distribution that is believed to be beneficial in enhancing interactions between the grains and an advancing crack tip over a wide range of crack lengths. Samples prepared in this study showed high retained strengths at elevated temperatures (>500 MPa at 1200°C) and fracture toughness values as high as 10 MPa$\sqrt{m}$.

Materials technology support was provided for an Industrial Technologies Program to assist contractors in developing high-temperature heat exchangers. Materials exposed to simulated steam-reformer environments were characterized to support selection of candidate materials for further testing at ORNL. This work was a cooperative effort with the Corrosion Science and Technology Group.

Characterization work was conducted on a ceramic material for the NPR-MHTGR. The commercially available material, Coors AD85 alumina, is a candidate for use in large blocks as a core support insulator. Detailed mechanical and physical property measurements were made, which will be part of a design data base.

Work was initiated on adapting CBCF thermal insulation to other applications. A U.S. patent application entitled "Damage Tolerant Light Absorbing Material" represents the first product of this initiative.

Development work continues on new chemical sensors. Our award-winning Rapid Fuel Analyzer is being further developed for specific applications of interest to several sponsors, and licensing negotiations with a manufacturer are under way. Work continues on a simple hydrogen-selective sensor based on hydrogen absorption by Pd (patent application filed).

4.3 CERAMIC SURFACE SYSTEMS — *T. M. Besmann, P. J. Blau, W. Y. Lee, R. A. Lowden, J. C. McLaughlin, D. P. Stinton, and C. S. Yust*

The friction and wear properties of new materials for automotive and truck engines are being investigated to help reduce energy losses due to friction, increase the reliability of transportation components, and accelerate the growth of the U.S. advanced materials industry. Supported by several DOE programs, the ORNL tribology effort has focussed on three key thrusts: (1) the systematic analysis of the friction and wear behavior of promising new materials like silicon nitride-based ceramics and graphite-based composites, (2) the development of strategies for more cost effectively simulating engine wear conditions, and (3) the development and testing of novel surface coatings and films for friction and wear reduction.

Ceramics and carbon-graphites represent lightweight, energy-efficient materials for potential use in low-emission, high-efficiency engine designs. ORNL's unique, high-temperature testing systems permit studies of friction and wear of candidate materials at temperatures up to 1000°C in controlled environments. A survey of historical attempts at engine wear simulations has helped develop wear testing strategies for a new CRADA with GM Research Laboratories in the area of lightweight materials.

ORNL has conducted (among the first published) evaluations of the lubrication potential of newly discovered fullerenes (C_{60} molecules) used in powder form. This has been part of an Advanced Energy Projects, Office of Basic Energy Sciences, effort in developing CVD methods to create novel, self-lubricating materials comprised of solid lubricants embedded in ceramic matrices. The thermodynamic feasibility of co-depositing a lamellar solid lubricant, MoS_2, with a hard ceramic matrix such as TiN, Si_3N_4, TiC, or SiC was examined, and equilibrium calculations suggest that MoS_2 could be co-deposited with TiN, Si_3N_4, or SiC when appropriate chloride precursors were used.

Under the sponsorship of DOE's CTP, a special, multi-year project to reduce the machining cost of ceramic parts for engines has been initiated. Tasks of the new Cost-Effective Ceramic Machining effort are: technology assessment and future needs, advanced machining process development, ceramic machinability and related performance, structure and quality of machined surfaces, and environmental safety and health aspects of ceramic machining. The subcontracted projects are complemented by in-house research on ceramic machining in conjunction with the HTML Program and the DP Technology Commercialization Initiative.

A program supported by the U.S. Air Force, Office of Scientific Research, on basic studies of nucleation and growth in CVD was completed. Techniques for in situ observation of nucleation and growth using angular-resolved laser light scattering were accomplished using SiC growing on silicon. Electron microscopy using lattice imaging has revealed specific, independent nucleation sites where nano-scale features have grown epitaxially. Highly oriented etch pits were observed to form due to hydrogen etching of silicon and may offer preferred growth sites for SiC.

A seed money program to develop parameters for codepositing molybdenum silicides with Si_3N_4 has been completed. It was demonstrated that crystalline Si_3N_4 containing molybdenum silicide could be deposited at high rates at temperatures as low as 1250° C. Work elsewhere has indicated that significant deposition rates of crystalline material were possible only at temperatures in excess of 1400° C. The results of this work have led the Naval Air Development Center to fund work at ORNL on Si_3N_4-based coatings for protecting C/C.

A CTAHE Program has been investigating the problem of corrosion of SiC and Si_3N_4 heat engine components by molten Na_2SO_4 salts, which are formed from impurities in fuel and air. A number of oxides have been identified that may protect these components from corrosion. Among these, Ta_2O_5 was selected as one of the most promising candidates, and CVD techniques have been developed to deposit it onto SiC substrates. Preliminary corrosion tests with 15 mg/cm^2 of Na_2SO_4 at 1000° C showed no degradation of the CVD-deposited coatings.

The U.S. Air Force Wright Laboratories has sponsored an effort to model chemical vapor infiltration (CVI) for the fabrication of continuous fiber-reinforced ceramic composites. A 3-D process model using a steady-state, finite-volume technique has been developed together with the Georgia Institute of Technology. An additional task requested by Wright Laboratories is to design and construct a scale-up, forced CVI unit to demonstrate the fabrication of turbine rotor subelement. The furnace has been acquired and is currently being installed.

Fiber-reinforced, thick-walled tubular composites of different fiber architectures (3-D braided, filament wound, and cloth wrapped) were fabricated using the forced CVI process under a Fossil Energy AR&TD Program. The fiber architectures were designed to tailor the mechanical properties for applications such as combustors, burner tubes, heat exchangers, headers, hot-gas filters, and even rotors for gas turbine engines. Composite tubes were nondestructively characterized at ORNL using radiography and CT. CT was particularly useful in detecting delaminations and voids within the composites. Mechanical characterization was initiated at Virginia Polytechnic Institute using tensile testing.

Fabrication of full-scale, fiber-reinforced candle filters (60 mm diam and 1.5 m long) continues in a collaborative effort with the 3M Company under a Fossil Energy-supported effort. Candle filters have been fabricated from Nextel (alumina-boria-silica) and Nicalon™ (Si-C-O) fiber preforms and infiltrated with an SiC matrix. Current filters are fabricated from filament-wound or braided structures for strength and chopped-fiber surfaces for permeability. Chopped-fiber surfaces have been engineered to simulate the permeability of commercial Schumacher candle filters.

An AIC Project to develop TiB_2-matrix composite cathodes for the reduction of aluminum continued this period. Efforts focussed on the efficient fabrication of 6-mm-thick disks of relatively uniform density. Arrangements have been made for Alcoa Aluminum Company to test the material for use as Hall-Heroult cell cathodes. A license for the technology has been acquired by Advanced Innovative Technologies, Inc.

Under the Fossil Energy AR&TD Program, alternatives to the oxidation-susceptible graphite inter-layer in SiC Nicalon™ composites are being investigated. Boron-containing materials offer improved oxidation resistance through the formation of a glass layer that can flow and seal the surface of the underlying material, protecting it from further attack. Boron-doped carbon and boron nitride interface coatings were thus examined to improve the oxidation resistance of the composites. Beyond a minimum concentration, boron doping of the carbon layers enhanced the short-term oxidation resistance of the composites (24 h at 1273 K in air). Boron nitride interface coatings also produced improvements in strength retention after oxidation; however, the composites were somewhat embrittled. The embrittlement appeared to be a result of fiber decomposition caused by oxygen in the as-deposited BN interlayers.

4.4 STRUCTURAL CERAMICS — *P. F. Becher, K. B. Alexander, A. Bleier, C. H. Hsueh, H. T. Lin, and S. L. Hwang*

Our efforts focus on both theoretical modeling and observations of crack propagation, fatigue, and creep in ceramics and composites to identify and characterize the mechanisms that contribute to improving their mechanical behavior. The models are systematically tested against a combination of experimental results. Detailed microstructural characterization is also conducted that allows the microstructural (e.g., interfaces, GBs, grain size, and shape) parameters to be incorporated into materials design concepts. Studies of materials processing are employed to (1) develop the microstructural features suggested by the models and (2) understand the mechanisms involved in the generation of such microstructures. The underlying objective is to understand how to develop toughened ceramics with greater mechanical performance capabilities. To this end, collaborative efforts are conducted to also explore how the toughening mechanisms may influence other mechanical properties (e.g., fatigue, creep).

4.4.1 BES Tasks

4.4.1.1 Transformation toughening

During this period, constitutive models of the martensitic transformation in zirconia behavior and the associated transformation-toughening response that includes key microstructural parameters have been developed and validated by experimental results. These studies involved collaborative research with M. V. Swain, University of Sydney; D. J. Kim, Korean Institute of Science and Technology; and E. F. Funkenbusch and R. Plovnick, 3M Corporation.

One of the important findings was that the scaling of internal stress concentrations with grain size promotes the transformation in tetragonal zirconia ceramics. This suggested that the transformation in ZTA composites would be a function of zirconia content as well as grain size. To evaluate this response, it was necessary to exploit colloidal processing principles to develop uniform, dense two-phase ceramics where the grain size of each phase can also be controlled. Complementary studies determined the energetics and kinetics of grain growth in colloidally processed alumina-zirconia composites containing up to 40 vol % zirconia. The growth of grains of each phase is coupled; that is, the growth rate of the faster growing phase (i.e., alumina for zirconia contents less than 50 vol %) is reduced by the slower growing phase. Utilizing this, it is possible to develop a sintering cycle for each composition to achieve the desired grain sizes. Collaborations with O. O. Omatete and M. A. Janney of ORNL in research supported by the AIM Program, Office of Industrial Technology, have extended these findings to produce ZTA composites by gel-casting combined with conventional sintering and by microwave sintering of colloidally processed composites.

Next, the residual stresses developed within the alumina and zirconia grains due to the thermal expansion mismatch (TEA) between these two phases were determined by neutron diffraction techniques in collaborative studies with X. L. Wang, C. R. Hubbard, J. A. Fernandez-Baca, and S. Spooner, ORNL. These results confirm that the TEA stresses in the zirconia increase with decrease in zirconia content. Experimental and theoretical studies show that the increase in the TEA stresses is a major factor in the sensitivity of the transformation to increase in grain size with decrease in zirconia content. Experiments with ZTA composites confirmed that the rate of increase in the martensite start temperature with zirconia grain size increased with decrease in zirconia content. The transformation toughening in ZTA composites was then shown to increase with zirconia grain size and content consistent with the theoretical predictions. Utilizing the results of these processing-microstructural evolution and transformation behavior studies, sintered ZTA composites with toughnesses and strengths approaching 15 $MPa\sqrt{m}$ and 900 MPa, respectively, were produced. Key to this has been understanding how microstructural parameters control the transformation behavior and how to systematically develop the desired microstructural characteristics by appropriate processing routes.

4.4.1.2 Reinforced ceramic composites

In the past, crack-bridging processes were characterized in whisker-reinforced ceramics (WRC) and theoretical treatments developed to describe the toughening behavior in reinforced systems. This, combined with experimental studies, helped define the contributions of interfacial, whisker, and matrix characteristics. These findings were then extended to include the toughening behavior for other types of discontinuous reinforcing phases and now form the basis for the microstructural design of toughened ceramics. Increasing emphasis is now placed on the evolution of these materials design concepts for elevated-temperature ceramics systems. More recent studies have also shown that WRC exhibit considerable cyclic fatigue resistance (with R. O. Ricthie, University of California-Berkeley) due to crack bridging and resistance to thermal stresses due to both greater toughness and thermal conductivity (with G. A. Schneider, Max-Planck-Institut für Metallforschung).

Our studies of self-reinforced silicon nitride (SRSN) are a natural progression of our findings in WRC. These studies indicate that toughening due to the formation of elongated silicon nitride grains should scale with the grain diameter and the volume content of the larger elongated grains. Initial studies confirm these predictions. The toughening response is predicated upon (1) the mechanisms controlling elongated grain growth (collaborative studies with M. J. Hoffmann, Max-Planck-Institut für Metallforschung) and (2) debonding of the elongated grain-GB phase interface during crack extension. Experimental studies are now addressing the material factors influencing debonding at the silicon nitride-oxynitride glass interfaces and the influence of microstructure (e.g., grain diameter and length) on the fracture resistance in the presence of selected GB phases. In addition, the microstructural design of SRSN ceramics requires knowledge of the crack-tip interactions with the microstructure and an understanding of the influence of the GB phases. This will be accomplished by (1) high-resolution SEM studies of crack-tip processes combined with (2) characterization of the grain interfaces using analytical and HRTEM of SRSN ceramics containing selected additives.

Furthermore, an extensive body of analytical models based on closed-form solutions has been developed to characterize the interfacial properties and fiber displacement response in brittle fiber-reinforced ceramics critical to the development of advanced composites. Recently, the analytical solutions were simplified with negligible sacrifice in accuracy to facilitate their application to the analysis of interfacial properties using test techniques measuring the load-displacement response of a fiber embedded in a matrix. Applicable to indentation- (e.g., microhardness or nano-indentor systems) or pullout-type tests used by most researchers, the analyses now provide a methodology for designing interfaces and testing their actual performance. The results of these studies have involved collaborations with M. C. Lu, Texas A & M University, and T. Kishi, Tokyo University, and are now being incorporated in research supported by the CFCC Project, Office of Industrial Technologies, and the AR&TD Materials Program, Office of Fossil Energy.

4.4.2 AIM Task

4.4.2.1 Intermetallic bonded oxides

Approaches that offer the potential of developing strong, tough ceramic-based composites for applications involving temperatures up to 1000°C are of considerable interest. One avenue is to develop advanced cermet-type composites utilizing the ceramic as the matrix to develop high hardness, strength, and chemical resistance in combination with a ductile metallic phase to provide toughness. However, little attention has been paid to developing cermet composites with higher temperature capabilities. The advances in nickel aluminide-based and similar intermetallics that can exhibit ductility and excellent mechanical properties to temperatures approaching 1000°C offer new opportunities to develop advanced cermet composites. Current efforts seek to develop intermetallic-bonded, oxide- and non-oxide-based (T. N. Tiegs, Ceramic Processing Group) composites with improved strength and toughness for such intermediate temperature applications.

Model composite studies employing intermetallic wires embedded within an oxide matrix reveal that plastic deformation accompanied by pullout of the intermetallic phase imparts up to a threefold increase in toughness in alumina containing only 1 vol % intermetallic wires. These studies also provide a technique to evaluate how the deformation behavior of the intermetallic phases of different compositions can be altered when constrained in a rigid matrix and subjected to various degrees of bonding to the matrix. When the aluminides are incorporated as a dispersed phase in alumina, the toughening achieved is a function of the shape of the aluminide particles. This is a result of the negligible bonding between the alumina and the nickel aluminide when using conventional processing, and thus deformation of the aluminide particles occurs only when their shape provides some locking of the particles into the matrix. However, by controlling the aluminide particle shape, toughness increases of twofold are achieved and maintained to temperatures of up to 700°C in alumina containing 10 vol % nickel aluminide. Current studies are exploring processing techniques and alloys that promote wetting of the oxide ceramic by the aluminides to further enhance the toughening effects.

4.4.3 CTAHE Project Task

4.4.3.1 Creep response in advanced ceramics

The creep response of ceramics can be strongly influenced by the stress state; in some materials, the creep rates decrease when the stress is changed from tensile to flexure to compression for the same temperature and applied stress levels. This can often be attributed to the promotion of cavitation damage by tensile stress components; the stress level for the onset of cavitation is decreased with a shift from flexure- to tensile-applied stress states. To clarify this behavior and understand the effects of material characteristics, tensile creep measurement facilities for use in air up to 1600°C that allow for testing of small samples of materials under development were designed and installed. Comparison of results for fine-grained alumina and SiC whisker-reinforced alumina in compression, flexure, and tension revealed no differences in the creep rate-applied stress responses until the stress to initiate extensive cavitation was exceeded. Similar studies of various silicon nitride ceramics are under way to characterize the influence of GB phases introduced by densification additives and grain size and shape.

At the same time, approaches to improve the creep resistance of ceramics are sought by examining the influence of microstructure and composition. For example, SiC whisker-reinforced aluminas show improved creep resistance with (1) increases in whisker content to about 25 vol % where greater whisker contents result in promoting oxidation and creep and (2) increase in alumina grain size. In the case of SRSNs containing elongated grain structures, changes in the densification additives impact creep rates. Ceramics produced using selected combinations of SrO, La_2O_3, Y_2O_3, and Al_2O_3 to alter GB phases have been examined. The results support the concept that the introduction of additives that either produce phases with increased eutectic temperatures or tend to form more refractory glass phases promotes creep resistance.

4.5 MATERIALS THERMAL ANALYSES — *T. G. Kollie, R. S. Graves, G. M. Ludtka, G. Mackiewicz-Ludtka, K. E. Wilkes, and D. W. Yarbrough*

The Materials Thermal Analyses Group conducts research and monitors subcontracts to other installations primarily for the DOE's Assistant Secretary for Conservation and Renewable Energy in the areas of advanced thermal insulation for buildings, evaluation of existing materials for building insulation, and technology transfer to the buildings industry. A new area of research for the group, which is conducted for DOE's DP, is modeling of thermal effects occurring during processing of materials to predict microstructures, thermal stresses, and properties in the materials resulting from the processes. Other research is performed for the Environmental Protection Agency (EPA), the Department of Defense, and other DOE programs and facilities in areas related to thermal insulation, properties of materials, and thermal processes.

Field management is provided for the materials part of the Building Thermal Envelope Systems and Materials Program conducted by ORNL for the Building Systems and Materials Division of the Office of Buildings Energy Research of DOE. This program addresses the development and characterization of new and existing insulation materials for buildings and refrigeration equipment. The Materials Program goals are to develop new materials that can reduce building energy consumption by 20% by 2010 and are cost competitive for their application.

Powder-filled evacuated panels (PEPs), with absolute pressures near 1-mm Hg pressure, provide an alternative insulation with a much higher initial R-value (R-25/in.) than CFC insulation (R-8/in.). The major efforts of the program have been directed toward development of lower-cost, higher-R-at-higher-pressure powders to improve the thermal performance of PEPs. A secondary research effort has been directed toward identification of low-permeability barrier material to encapsulate the powder and retain the vacuum and thereby extend the lifetime of the PEPs. A CRADA (ORNL 91-0042) with the Appliance Research Consortium was signed to develop a test procedure to determine the lifetime of PEPs in dry air. A CRADA with PPG Industries (ORNL 91-0071) was signed to determine the relationship between morphology of silica particles and the thermal conduction mechanisms operative in the silica powders. Four new powders have been identified with promising thermal performance; patent disclosures have been filed with the DOE on these powders. We submitted a patent application to the U.S. Patent Office for the gauge we invented to measure the internal pressure of PEPs nondestructively. A license for this gauge has been written with VacuPanel, Inc. Construction on a facility to fabricate experimental PEPs was completed. (The work on powders and barriers has been funded by the EPA and DOE.)

A CRADA (ORNL 90-0028) has been established with the Polyisocyanurate Industry Manufacturers Association, the Society of the Plastics Industry, EPA, and associated trade organizations and industrial members to evaluate the thermal performance of rigid foam blown with CFC-11 (control), HCFC-123, HCFC-141b, and two blends of HCFC-123/HCFC-141b. Industry-produced boards are being evaluated by field tests in the ORNL Roof Thermal Research Apparatus (RTRA) and by lab thermal resistance (R-value) tests of thin-board specimens. After 510- to 645-d exposures in the RTRA, the R-values of the foams decreased by about 13 to 26%. The R-value change is accelerated in the thin boards, and this change in R produced two linear regions when the conductivity (1/R) is plotted versus time$^{1/4}$/thickness, with the slopes of these two regions proportional to the effective diffusion coefficients for air components and the blowing agents. The R-values after 10- and 20-year aging were predicted for the unblended and blended blowing agents, respectively. Plans for the possible extension and broadening of this CRADA were presented to the industrial partners, who currently are evaluating them.

We are developing a procedure to measure accurately the resistivity of high-R insulation such as PEPs. We are employing our Heat Flow Meter Apparatus (HFMA), which is a commercially available device. Because specimens of the high-R materials must be measured as a composite with lower-R materials, a computer model of the heat flow patterns must be employed to compute the R of the specimen from that measured by the HFMA. To do this, we have modified the HEATING-7 heat transfer code to run on an IBM-compatible 386 computer. A user-friendly interface for this code is being written to facilitate use by the insulation industry. In addition, we have modified the HFMA by inserting a 5 by 6 array of heat flux meters to measure the 3-D heat flow in the HFMA; these data are required by the HEATING-7 code. This work will be complete in FY 1994.

The ORNL Unguarded Thin Heater Apparatus was modified so that the heat- transfer conditions in attics insulated with loose-fill insulation could be simulated for heat flow-up. Results with this device showed that the R of fiberglass insulation decreased when the temperature difference across the insulation exceeded about 20°C, in agreement with the results obtained in the ORNL Large-Scale Climate Simulator. A patent disclosure for this apparatus was filed with the DOE. The decrease in R of the fiberglass loose-fill insulation is due to the establishment of natural convective cells within the insulation. The temperature gradient necessary to produce these cells in loose-fill insulation can be predicted from measurements of the air flow permeability of the insulation. A device to measure this property was assembled and will be developed in FY 1993.

Besides the above-mentioned CRADAs, we performed technology transfer in several ways. For example, we measured the thermal conductivity of gas-filled panels for Lawrence Berkeley Laboratory. These measurements demonstrated that their panel designs did not achieve the resistivity of the gas without conduction due to heat conduction through the solid material forming the enclosure of the panels. We participated in the writing of ASTM test procedures by attending meetings of the ASTM C 16 Committee on Thermal Insulation and by participating in interlaboratory comparisons using proposed test procedures to establish the required precision and bias statements. For example, we participated in an interlaboratory comparison on ASTM procedure C 335 for measuring the thermal conductivity of pipe insulation. One member of our group, R. S. Graves, served as co-chairman of the "Second Symposium on Insulation Materials: Testing and Applications" sponsored by the ASTM and held in Gatlinburg, Tennessee, in October 1991. We measured the thermal conductivity of low-density cellulose products that are relatively new to the marketplace and compared these data with product labels and previous ORNL measurements on cellulosic insulation. Excellent agreement (4%) was obtained with both of these correlations.

The work for DOE's DPs will be conducted as two CRADAS. The first is with GM (ORNL 92-0113) to develop lightweight materials for transportation applications. The work on this CRADA began in October 1992. The second CRADA (ORNL 92-0077) is with the National Center for Manufacturing Sciences and seeks to develop a computational tool/methodology (based on finite element techniques) to predict the effects of heat treatment on the size and shape of industrial, quenched parts. This CRADA is awaiting final approval by the partners.

5. NUCLEAR FUEL MATERIALS

M. J. Kania

The Nuclear Fuel Materials Section has as its primary objectives (1) the qualification of advanced nuclear fuel materials performance during in-reactor operation and under off-normal conditions, (2) the characterization of fission product transport and behavior in core materials under normal and off-normal conditions, and (3) the development of performance models and codes for use in confirmatory design analysis and safety-related assessments. These objectives are accomplished through management of fuel development activities at the subtask level for two ORNL reactor programs and three international cooperative programs and through the coordinated activities of five technical groups within the section with shared expertise and resources in fuel materials characterization, modeling, irradiation testing, unique remote equipment development, and facility operation.

Program guidance and coordination are provided for two separate DOE-sponsored reactor programs by the section. For the Nuclear Energy (NE) MHTGR Program, this includes the multidivision activities of the Fuel Materials Development and Fission Product Behavior Subtasks and the management of three international programs: the Fuels, Fission Products, and Graphite Subprogram within the U.S./Germany Umbrella Agreement on High-Temperature Reactor Development; the U.S. DOE/JAERI Collaborative Program for Coated Particle Fuel Performance Testing; and the U.S. DOE/Commissariat A L'Energie Atomique (CEA) Collaborative Program on the Corrosion, Migration et Distribution Irradiation Experiment (COMEDIE) Loop Fission Product Behavior Tests. In the ANS Program, guidance is provided for the Fuel Materials Development Subtask.

Research activities of the five technical groups include the operation and development of specialized remote facilities for PIE and handling of irradiated fuel materials [Irradiated Fuels Examination Laboratory IFEL)]; the evaluation of irradiated fuel performance and fission product characterization, including microstructural characterization and specialized remote equipment development (Fuel Materials Evaluation Group); in-reactor testing and performance evaluation of fuel materials (Fuel Materials Testing Group); characterization/evaluation of fuel and fission product behavior under off-normal conditions [High-Temperature Fuel Behavior (HTFB) Group]; and model development based on fundamental understanding of fuel materials and fission product behavior (Fuel Performance Modeling Group).

Support for these efforts is provided through three main DOE sources: (1) the NE–MHTGR Program Fuel Materials Development and Fission Product Behavior Subtasks; (2) the NPR-MHTGR Fuel Performance Subtasks (normal operating conditions and off-normal operating conditions), the Fuel Performance Model/Code Development Subtask, and the Fission Product Transport Subtask; and (3) the ANS Fuel Materials Development Subtask.

5.1 IRRADIATED FUELS EXAMINATION LABORATORY — *C. E. DeVore*

The IFEL is a major hot cell facility located in Building 3525. The purpose of the facility is to handle irradiation experiments or irradiated materials for examination, testing, evaluation, or processing. Operation of the IFEL must be in a safe and efficient manner through compliance with all safety standards, orders, and regulations. The facility must be maintained and updated with both documentation and equipment. Much of the in-cell equipment used for handling experimental work is nearly 30 years old and has reached its expected life. Equipment failures requiring maintenance have become more difficult to perform because of the highly contaminated condition from years of service. Maintenance can be too costly in terms of personnel exposure. New decontamination techniques are being sought that will allow equipment maintenance with lower exposure until modern replacements can be installed. Facility safety documentation is being updated to reflect current operations and hazards. Old procedures are being reviewed for revision to meet today's rigor of documentation.

During the report period, programmatic work, as well as facility upgrade work, was accomplished. Programmatic work included the receipt, remote disassembly or machining, and either transfer to the Irradiated Materials Examination and Testing Group at Building 3025E or examination by the Fuel Materials Evaluation Group at Building 3525. The experimental designations and their program sponsors processed during this report period were HRB-17, -18, -21, HTK-7 (NE-MHTGR); NPR-1 and -2, HTN-1 (NP-MHTGR); JP-10, -11, -13, -16, -18, -19 (Fusion); crack-arrest specimens (NRC-HSSI); and HANSAL (ANS). A significant effort to restart ORNL's Iridium-192 Isotope Program was initiated with the demonstration of equipment, the writing of procedures, the completion of a successful readiness review, and the successful processing of about 300,000 Ci of ^{192}Ir.

In-cell, high-radiation-level waste material, which had been accumulated from many years of operation, was transferred to the solid waste storage area (SWSA). Obsolete equipment stored in the hot equipment storage area of the facility was removed and also transferred to SWSA.

Recurrent and unexplained personnel contamination occurrences resulted in the decision to seek advice on radiation protection practices in the facility. As a first priority, a detailed characterization was initiated and completed with the identification of approximately 100 spots of previously unknown contamination areas within the facility and the surrounding area outside the facility. Many of these areas were fixed contamination, but one identified area inside the facility contained removable contamination in an overhead area. With the potential for contamination release to the floor below and tracking throughout the facility, this area was decontaminated. Radiation protection staff were increased to provide increased surveillance of the facility, screening of materials and equipment upon entry and exit, and better coverage of the many jobs occurring in the facility each day. The use of pre-job briefings involving facility staff and support personnel has led to a better understanding and working relationship between operations and support personnel.

The facility safety documentation, which includes an Operational Safety Requirements document and the Phase I Hazard Screening document, was prepared as part of ORNL's Phased Safety Analysis Report Update Program.

To provide a more responsive organization to the requirements of the "new culture" desired by DOE for the operation of nuclear facilities, additional personnel were assigned for the management, operation, and maintenance of the facility.

Selected operating procedures were revised on an as-needed basis. An operator training program is now being updated for the certification of operating personnel, both chemical operating staff and supervisors.

A detailed shielding characterization and integrity survey was performed on the main first-floor cell areas and peripheral areas on the second floor as the result of identified weak shielding at other DOE facilities. Weak areas identified at this facility were either mitigated by engineering corrections or through administrative controls.

The facility has been visited by many organizations and groups for appraisals and audits including DOE-NS, MMES Corporate Audit. DOE Functional Appraisal, ORNL Radioactive Operation Committee, Transportation Safety Committee, DOE Tiger Team, and DOE Site Personnel.

The facility was required to provide an alternate method to dispose of low-level liquid waste (LLLW) after implementation of the federal facilities agreement on January 1, 1992. A trucking station that pumps LLLW from the facility's LLLW collection tank to a transportable tanker was placed into service after completion of a formal readiness review. Under this condition, although limited in the quantity of LLLW generation, facility operation has continued.

5.2 FUEL MATERIALS EVALUATION — *N. H. Packan*

During the past year, PIE commenced on three major fuel irradiation experiments: HRB-21 of the NE-MHTGR Program and capsules NPR-1 and -2 for the NP-MHTGR Program. PIE completed on HRB-21 included gamma scanning of the entire capsule and the fuel holders individually; cutting open and removal of fuel compacts, piggyback specimens, and flux monitors; and dimensional measurements of the fuel compacts and holders. At year's end, deconsolidation of several compacts to individual particles, metallography of other compacts, and automated gamma analysis of several thousand particles using the irradiated microsphere gamma analyzer apparatus were all under way.

The disassembly of the NPR-1 and -2 capsules was started late in 1992, with half the fuel compacts removed and prepared for fission gas retention tests at another site. Metallography was also conducted on selected fuel materials for a WFO program. Support for the HSSI Program was in the form of providing dosimetry to three irradiation capsules (HSSI/10-1, -2, and -5), as well as participating in an experiment to measure the neutron fast-to-thermal flux ratio at the wall of the HFIR pressure vessel.

Capability improvements realized in 1992 included improved equipment, techniques, and procedure preparation for: metallographic specimen preparation of individual coated fuel particles and fuel compacts, developing equipment and processes for fuel compact deconsolidation, design and fabrication of a capsule disassembly fixture with force gage, reviving the gamma scanner facility, and the design and installation of an in-cell video zoom microscope to assist in metallographic specimen preparation.

5.3 HOT CELLS REVITALIZATION PROGRAM (HCRP) — *P. E. Arakawa*

The HCRP was initiated in FY 1987 in response to Laboratory management's request to consolidate metallurgical examination hot-cell work into two facilities, Buildings 3025 and 3525. This work is scheduled to be completed in two phases; Phase I will bring both Buildings 3025 and 3525 to fully operational status, and Phase II will include correcting remaining design deficiencies and will modify or add systems that will promote safe and efficient operations in the hot cells of Buildings 3025 and 3525. Phase II is planned to be completed under a Multiprogram, General-Purpose Facility, FY 1996 Line Item.

During FY 1992, approximately $1,000,000 was spent in support of the revitalization program. The major emphasis of this work in Building 3025 included the fabrication and delivery of two new hot cell windows, the fabrication and delivery of one new 1-ton hot cell crane, the upgrading of the hot cell shielding integrity, and remediation of legacy contamination within the facility.

The major emphasis of work in Building 3525 included starting the fabrication of three new 3-ton hot cell cranes valued at $150,000 and starting the fabrication of one new electromechanical hot cell manipulator valued at $350,000. This equipment will replace existing 30-year-old, obsolete, and contaminated equipment, and is expected to be completed in the third quarter of FY 1993. Also accomplished was the upgrading of the hot cell shielding integrity, which was provided to reduce the radiation exposures to facility personnel in accordance with as low as reasonably achievable principles. The installation of five new master/slave manipulators was also initiated in the decontamination cell, which will provide safer and more reliable operations, and is expected to be completed in the first quarter of FY 1993.

A trucking station that was fabricated, installed, and tested in FY 1991 was given approval to operate in FY 1992. This system allows the sampling and transfer of LLLW generated in Building 3525 to a Waste Operations tanker truck until alternate methods of LLLW removal are in place.

5.4 HIGH-TEMPERATURE FUEL BEHAVIOR — *W. A. Gabbard*

The HTFB Group completed the design and development of the Core Conduction Cooldown Test Facility (CCCTF). This facility provides the capability to evaluate irradiated ceramic nuclear fuels performance under loss-of-coolant events characteristic for the MHTGR. The development of the CCCTF covered a period of six years and a capital cost in excess of $1 million. The installation of the first high-temperature furnace and its attendant control, monitoring, and utility systems into a remote hot cell was completed in 1991. Full-scale, in-cell operation testing and fission product detection calibrations followed in 1991, and in 1992, real-time tests with irradiated fuel materials were initiated for the NE-MHTGR and NP-MHTGR Fuel Development Programs.

Under routine operation, the CCCTF is expected to monitor and collect gaseous and metallic fission products released from irradiated fuel for times as long as 1000 h at specimen operating temperatures up to 1000°C in a controlled atmosphere. For temperatures in excess of 1600°C, testing times are reduced. Key components of the system include: (1) high-temperature furnaces with operating temperatures up to 2000°C, (2) on-line fission product collection systems for gaseous species using LN_2-cooled charcoal traps and condensible species using a removable cold-finger assembly inserted into the furnace heat zone, (3) automated control and data collection systems, and (4) a gas purge system with capacity for injection of low levels of coolant impurities. Additional capabilities are available for remote fuel handling, furnace component replacement, and fission product mass balance determinations.

5.4.1 NPR-MHTGR Accident Condition Tests

In 1991, two tests were initiated to determine the behavior of irradiated, highly enriched uranium (HEU) uranium oxycarbide (UCO) TRISO-coated fuels under accident conditions. Two tests, one at 1400°C for 300 h and a second at 1600°C for 100 h, were planned, executed, and a detailed fission product analysis completed. The details of the tests and the fuel performance results are reported in ORNL/NPR-92/9, *HRB-17 and HRB-18 HEU TRISO UCO Unbonded Irradiated Particle Core Conduction Cooldown Tests*. These tests successfully demonstrated the capabilities of the CCCTF while gathering valuable performance data for the NPR-MHTGR Fuel Development Program. The 1400°C test, terminated after approximately 260 h, exhibited some metallic fission product release, not due to particle failure but due to contaminations from other failed particles during in-reactor testing. The 100-h, 1600°C test showed significant release of metallic fission products from the HEU UCO TRISO-coated particles. The fraction of fuel exhibiting significant ^{134}Cs and ^{137}Cs release amounted to 3%.

5.4.2 NE-MHTGR Accident Testing

A demonstration test of the continuous operation of the CCCTF for 1000 h at 1600°C was completed in fulfillment of an NE-MHTGR Fuel Development Program Milestone. The results of this demonstration test provided: (1) a real-time demonstration of the facility with irradiated fuel materials under typical operating conditions and (2) on-line performance data for U.S.-fabricated HTGR fuels of sufficient duration to observe both metallic (after 200 h at temperature) and gaseous (after 700 h at temperature) fission product release. The metallic fission product release observed represented nearly 35% of the ^{137}Cs inventory present, while the gaseous fission product release represented only 0.25% of the ^{85}Kr inventory.

Both the NE- and NPR-MHTGR Fuel Development Programs require accident testing under air and moisture ingress conditions. Conceptual development of a second furnace system to include air ingress capability and a third furnace system to include moisture ingress capability was initiated. Procurement of the second furnace was completed and its operation demonstrated; the third furnace system procurement was initiated.

5.5 FUEL MATERIALS TESTING — *J. T. Parks*

On October 1, 1991, there were three irradiation experiments in progress in the HFIR in support of the MHTGR Program. One capsule, designated HRB-21, was being irradiated in support of the Civilian MHTGR Fuel Development Program, and two capsules, NPR-1 and -2, were being irradiated in support of the NPR Fuel Development Program.

5.5.1 Capsule HRB-21

Irradiation capsule HRB-21 began irradiation with HFIR fuel cycle 298 on June 20, 1991, and concluded with cycle 302 on November 21, 1991, for a total of 105 effective-full-power-days (EFPD) of operation. The irradiation was conducted in position RB-3B of the HFIR RB irradiation facility. Capsule HRB-21 was scheduled for a six-cycle irradiation but was terminated after the fifth cycle (302) due to loss of temperature control.

In-reactor fuel performance for capsule HRB-21 was monitored by measuring the fission gas release rate-to-birth rate ratio (R/B) of selected krypton and xenon short-lived fission gases. The beginning-of-life performance was excellent as indicated by the ^{85m}Kr R/B at 2×10^{-8}. Shortly after the HFIR ascent to full power at the beginning of the second irradiation cycle (299), a jump in the ^{85m}Kr activity to about 5×10^{-7} was recorded, indicating onset of fuel particle failure. This activity continued to increase during this and subsequent irradiation cycles. The end-of-life ^{85m}Kr R/B was approximately 2×10^{-4} indicating a fuel failure fraction near the 10^{-2} range, compared to the predicted end-of-life results of ^{85m}Kr R/B of $<10^{-6}$ and a failure fraction of $< 2 \times 10^{-4}$, respectively, based on preirradiation characterization data. Although the fission gas release from the HRB-21 test fuel was significantly higher than anticipated, the test capsule generated high-quality data that will contribute to the overall R&D data base for the NE-MHTGR Fuel Development Program. Details associated with the irradiation are included in ORNL/TM-12238, *HRB-21 Irradiation Phase Report.*

PIE began with the shipment of the test train to the IFEL in February 1992. The PIE work schedule began shortly thereafter with inspection and photography of the capsule containments. Detailed destructive and nondestructive PIE efforts continued throughout FY 1992.

5.5.2 NPR-1

Irradiation of the NPR-1 test began with HFIR cycle 299 on July 25, 1991, and concluded with cycle 307 on May 29, 1992. The initial plan was to irradiate for six cycles, or about 130 full-power days, but the irradiation period was extended to eight cycles to provide additional on-line fission gas release data, following the onset of test fuel failure. The test was removed for cycle 305, while the final decision was being made to extend the irradiation period, then reinserted for cycles 306 and 307. The total irradiation time was about 170 EFPD.

Initially, the test fuel performed well within pretest predictions. The ^{85m}Kr R/B value was holding steady in the range of $\sim 8 \times 10^{-9}$ to $\sim 2 \times 10^{-8}$. However, during cycle 304, a significant increase in sweep gas fission product radioactivity was noted, indicating the possible onset of particle failures. The ^{85m}Kr R/B increased rapidly to about 5×10^{-5}. The sweep gas radioactivity continued to increase over the remainder of the test. Irradiation continued through the end of cycle 307. At the end of the test, the ^{85m}Kr R/B had increased to about 4×10^{-4}, indicating a particle failure fraction of $\sim 10^{-2}$, which exceeded the pretest predictions of $< 10^{-8}$ and $< 10^{-4}$, respectively, that were based on preirradiation data.

PIE for NPR-1 commenced with shipment of the capsule to the IFEL on December 3, 1992. The effort continues at this time and is expected to be completed in FY 1993.

5.5.3 NPR-2

Irradiation of the NPR-2 test began with HFIR cycle 300 on August 28, 1991, and concluded with cycle 307 on May 29, 1992. The initial plan was to irradiate for six cycles, or about 130 full-power days, but the irradiation period was extended to eight cycles to provide additional on-line fission gas release data, following the onset of test fuel failure. The total irradiation time was about 170 EFPD.

Initially, the test fuel performed well within pretest predictions. The ^{85m}Kr R/B value was holding steady in the range of $\sim 2 \times 10^{-9}$ to $\sim 1 \times 10^{-8}$. However, during cycle 304, a significant increase in sweep gas fission product radioactivity was noted, indicating the possible onset of particle failures. The ^{85m}Kr R/B increased rapidly to about 1×10^{-6}. The sweep gas radioactivity continued to increase over the remainder of the test. Irradiation continued through the end of cycle 307. At the end of the test, the ^{85m}Kr R/B had increased to about 1×10^{-4}, indicating a particle failure fraction of $\sim 10^{-2}$, which exceeded the pretest predictions of $< 5 \times 10^{-8}$ and $< 4 \times 10^{-5}$, respectively, that were based on preirradiation data.

PIE for NPR-2 commenced with shipment of the capsule to the IFEL on December 3, 1992. The effort continues at this time and is expected to be completed in FY 1993, in conjunction with the NPR-1 PIE.

5.5.4 Conceptual NPR Test Design Tasks

The NPR test schedule originally included several additional tests to be conducted at ORNL over the next few years. Significant effort was expended toward developing conceptual designs in support of that test matrix. Results of these efforts may be useful in the long-range test planning for the civilian program.

5.6 ADVANCED NEUTRON SOURCE FUEL DEVELOPMENT — *G. L. Copeland*

Fuel development work this year for the ANS included fabrication development, continued evaluation of the first irradiation capsule, fabrication of a second irradiation capsule, and continuation of the fuel performance modeling/irradiation damage simulation effort.

Fabrication development at ANL and Babcock and Wilcox focused on improving the homogeneity of U_3Si_2-Al dispersions. Characterization of the fuel and aluminum powders and appropriately matching the properties of the powders resulted in significant improvements in homogeneity. Several HFIR plates in which the silicide fuel was substituted for the oxide fuel were fabricated and met the HFIR homogeneity specification. Much of the effort at B&W was delayed while the homogeneity scanner was upgraded and converted to computerized data acquisition so that the dual fuel gradients required for ANS can be evaluated. Near the end of the year, fabrication began on a series of miniplates that will be used in safety tests in a pulsed reactor.

Evaluation of the first irradiation capsule, HANS-1, continued. About half of the microstructural analysis has been accomplished. Results thus far indicate good performance of the U_3Si_2 fuel particles at high temperature and fission rate. Higher magnification SEM is required to measure the fission gas bubble distribution for input to the fuel performance model. The specimens were shipped to ANL at the end of the year to obtain this examination and complete the conventional metallography. The second irradiation capsule was completed and is scheduled for insertion in the HFIR in January 1993.

Work continued at ANL on refinement of the fuel performance model. The mechanistic model is based on existing irradiation data, results from the HFIR experiments, and results from irradiation damage simulation experiments being performed at ANL using neutron and ion bombardment.

5.7 FUEL PERFORMANCE MODELING — *M. J. Kania*

The Fuel Performance Modeling Group participated in several international efforts related to fission product modeling under the auspices of the NE-MHTGR Program, provided data analysis of the results from on-line monitoring of the three irradiation capsules at HFIR, derived a revised model for cesium transport through SiC at high-temperature accident conditions, and provided input to NPR-MHTGR programmatic needs.

Staff participated in formulating an International Atomic Energy Agency (IAEA) coordinated research program (CRP) on fuel and fission product behavior in GCRs and attended an IAEA technical workshop on fission product behavior. Coordination continues between ORNL and the Forschungszentrum (KFA) on the ongoing cooperative PIE of the HFR-B1 irradiation capsule at Petten, The Netherlands, and Jülich, Germany. Staff were assigned to Petten late in the year to assist in the analysis of the irradiation data and the writing of the final PIE report.

As part of the U.S./Germany Umbrella Agreement for Cooperation in Gas-Cooled Reactor Development, staff were assigned to the KFA Jülich to work with German specialists in updating a German report on fuel performance and fission product transport modeling to include additional information from U.S. and other national GCR programs. This report, *Methods and Data for HTGR Fuel Performance and Radionuclide Release Modeling During Normal Operation and Accidents for Safety Analyses* (Forschungszentrum Jülich Report Jül-2721), is presently in press and will be used in conjunction with the above-mentioned CRP.

Analysis of irradiation data from irradiation capsules HRB-21, NPR-1, and NPR-2 was ongoing throughout the year. A detailed analysis of the on-line ionization gage measurements provided correlation of ionization pulse data to particle failure events. Staff were also assigned to Combustion Engineering General Atomics (CEGA) to assist in the writing of the *NP-MHTGR Fuel Design Manual Basis Report* (CEGA-002322, September 1992). A previously completed analysis appeared in print: B. F. Myers, "Effect of Water Vapor on the Release of Fission Gases from Uranium Oxycarbide in High-Temperature, Gas-Cooled Reactor Coated Fuel Particles," *J. Am. Ceram. Soc.* **75**, 686-93 (1992).

A revised model for cesium transport in SiC at high temperatures was developed and reported in ORNL/NPR-92/16, *Revised MHTGR High-Temperature Fuel Performance Models*.

6. PROGRAM ACTIVITIES

This section of the report deals with the program activities in which the M&C Division was engaged to a major extent during the report period. Brief statements of the purpose, nature, and scope are presented on the following programs sponsored by the U.S. DOE: BES-Materials Sciences, Electric Energy Systems, Reactor Materials, Conservation Materials, Space and Defense, Fossil Energy, Fusion Energy Materials, and High-Temperature Superconductivity.

6.1 BASIC ENERGY SCIENCES–MATERIALS SCIENCES PROGRAM — *L. L. Horton*

The Office of BES funds a wide range of research activities in the M&C Division. The majority of our funding comes from the Division of Materials Sciences. This program provides the fundamental basis for the division's core programs and a framework to foster the development of innovative materials and processes. The overall goal of the BES Program is to develop an understanding of structural materials and materials processes at all levels, from the atomic structure to the macroscopic properties. The program reflects the materials emphases within the division: structural ceramics/composites, high-temperature ordered intermetallic alloys, and radiation-resistant materials. It includes the research components required to better understand and utilize materials: synthesis, processing, fabrication, characterization, and development of models/mechanisms.

Research in synthesis and processing science includes the development of fabrication and joining techniques for advanced intermetallic alloys, ceramics, and composite structures. Intermetallics research includes fundamental studies of phenomena related to physical and mechanical properties, ranging from atomic bonding to environmental embrittlement. Investigations in the ceramics program are focused on establishment of basic microstructure-property relationships for the design of advanced ceramics and ceramic composites. The Welding Task continues to investigate the evolution and stability of microstructures and properties of weldments and serves as the coordinator for the national BES Welding Program. A strong first-principles theory effort is integrated with the alloy design program. Expansion of the theory program to include a first-principles ceramics theory effort is planned.

Important to all of the tasks is the development and application of advanced characterization techniques, including AEM, X-ray techniques, APFIM, MPM, and ion beam techniques. New techniques and instrumentation under development are the high-temperature MPM, the 3-D multielement atom probe, and the addition of an atomic force microscope to the MPM facility. X-ray optics for a multipurpose XRD beamline (UNI-CAT) at the advanced photon source are being developed along with the conceptual design for an X-ray microprobe (MICROCAT). Ion implantation is used to study defect interactions, radiation effects, and to modify surface-related properties of polymers and ceramics.

In the synthesis and processing area, we continue to participate in the BES Center of Excellence in Synthesis and Processing. This center represents a collaborative effort among the BES-funded materials laboratories to promote and coordinate synthesis- and processing-related R&D activities. Industrial involvement is a key feature of these research activities. Central management of the center is through Sandia National Laboratories (Albuquerque, New Mexico) with technical management distributed to five of the national laboratories; ORNL is responsible for the ceramics component of the center activities.

There is continuing increased emphasis, in the national BES Program, on radiation effects, especially with regard to the effects of neutron environments. In the past two years, the program has made major contributions to the understanding of mechanisms of RPV embrittlement. Fundamental studies of pressure vessel phenomena are jointly sponsored by the USNRC. In related activities, M&C staff continue to play a major role in the fuel element and corrosion studies for the development of the ANS.

The national program continues its strong support of national user facilities and programs. Through ORNL and the Oak Ridge Institute for Science and Education (ORISE), the BES Program supports the SHaRE Cooperative Research Program and the Oak Ridge Synchrotron Organization for Advanced Research (ORSOAR). The SHaRE Program allows scientists from universities, industries, and other national facilities to have access to facilities in the M&C Division, especially the AEMs, the APFIMs, and the MPMs. The ORSOAR Program supports an X-ray beamline at the National Synchrotron Light Source (NSLS) at BNL. This facility is used for cooperative research by scientists from more than 20 universities and industrial institutions that are part of a user group organized by ORNL and the ORISE.

This year, a new research project has been initiated under the Advanced Energy Projects Division of BES. This project is focussed on the development of novel composite coatings to control high-temperature friction and wear. It involves the use of CVD to deposit multiphase coatings containing high-temperature lubricants.

6.2 REACTOR MATERIALS — *P. L. Rittenhouse*

6.2.1 Liquid-Metal Reactor Materials Technology

During the year, members of the division served on the ALMR Working Group on Components. The activities of this group are in direct support of the General Electric-PRISM ALMR design and include task areas as described below.

Post-test examination was conducted on the B&W 76-MW prototype helical-coil steam generator that operated for about 5000 h at the Energy Technology Engineering Center in the early 1980s. A 14-in.-diam, single-ply bellows made of 316 stainless steel was metallurgically evaluated. The bellows had seen several years of service with flowing sodium at 260°C in the EBR-II reactor. Stiffness measurements were made both in tension and compression and compared with similar measurements on an archived bellows. Finally, long-term creep-rupture tests on types 304 and 316 stainless steel were continued to provide support for the development of 60-year ASME design stress allowables.

6.2.2 Civilian GCR Materials Programs

The DOE's GCR efforts continue to be focused on the MHTGR. ORNL is responsible for technology development relative to the low-enriched uranium UCO fissile and thoria fertile fuel particles; behavior and transport of fission products; properties and behavior of fuel block, reflector, and core-support graphites; and the properties of alloys and ceramics used in the reactor internals, vessel system, and heat transport systems. All but the fuels and fission product efforts are generic to the civilian MHTGR and to the MHTGR version of the NPR and are currently funded by DOE's NPR Program (see Sect. 6.2.3 for further discussion of status).

There were two major accomplishments in the fuels and fission products areas during the year. The first was the completion of irradiation of fuel capsule HRB-21 in the HFIR and initiation of PIE of the fuel compacts from this experiment. The second was the successful completion of fission product transport experiment BD-1 in the COMEDIE loop at the CEA facility at Grenoble, France. In this test, intentionally defected fuel was irradiated in an in-reactor, high-pressure loop to provide for plateout of fission products on simulated heat exchanger bundles. The bundles sections were then depressurized several times at different rates to study liftoff of fission products. PIE of the experiment is in progress. (See Sect. 5.8 for additional discussion of these tests.)

A low level of cooperative effort continued with Germany and Japan on fuels and graphites. An irradiation of U.S., German, and Japanese nuclear graphites was completed in the HFIR, and the PIE results were reported.

6.2.3 Materials Technology for the MHTGR NPR

Confirmatory development efforts on HEU UCO fuel, graphites, alloys, and ceramics for the MHTGR-NPR were continued throughout the year, and significant progress was made in all areas. Because of changes in the international situation, a decision to discontinue work on both the MHTGR and HWR versions of the NPR was announced by DOE on September 11, 1992. However, funding is to be provided through FY 1993 to allow for orderly closeout of all tasks and to perform further testing for risk reduction in specific areas.

Eight-cycle irradiations of HEU fuel compacts in capsules NPR-1 and -2 were completed in the HFIR. In both capsules, maximum burnups of 79% and fluences of 3.7×10^{25} neutrons/m^2 were achieved. The capsule averaged fuel compact temperature in NPR-1 was very close to 1000°C and that in NPR-2 was approximately 800°C. Disassembly of the capsules was initiated in December 1992; PIE is scheduled to be conducted through July 1993.

Two heating experiments on unbonded HEU UCO fuel particles were conducted in the CCCTF. In one of the tests, the fuel particles were ramped to 1400°C and held at temperature for 259 h; the other test involved a 100-h exposure at 1600°C. The CCCTF system was monitored on-line for radioactive cesium and krypton releases, and all particles were individually gamma scanned before and after heating to quantify fission product releases. The results of these heat-up tests were reported in ORNL/NPR-92/9.

Formal plans and procedures for all mechanical and physical property areas of graphite development were approved, and testing was initiated relative to tensile properties, fatigue and fracture behavior, and thermal physical properties. Irradiation of two additional graphite capsules (HTN-2 at 600°C and HTN-3 at 900°C) was completed in the HFIR, and PIE is scheduled to begin early in 1993.

Testing was also begun on the Alloy 800H material to be used in the in-reactor components (core barrel, lower core-support structure, etc.). Tensile testing was completed on unaged base metal, weld metal, and HAZ specimens; creep-rupture, low-cycle fatigue, and fracture mechanics testing was initiated on Alloy 800H specimens in these same conditions. Scoping irradiation studies of Alloy 800H weldments were also begun.

Metallurgical examination and evaluation of materials associated with the FSV GCR ringheader were begun and will continue through the first half of 1993. Metallography, SEM, hardness testing, and tensile and creep-rupture tests are being used to determine the cause of the cracks observed in the ringheader body and to evaluate the metallurgical condition of the ringheader lead-in-tubes, the exit steam pipe, and all weldments.

6.2.4 Materials Technology for the HWR NPR

A three-year effort to provide supplementary mechanical property and metallurgical structure data on HWR primary system boundary materials was completed. Emphasis was on the performance of 316LN stainless steel in the temperature range 25 to 150°C.

A series of corrosion exposures of Al-8001 fuel cladding materials in flowing water under heat-transfer conditions was completed and evaluated. The growth of oxide films was characterized by in-test measurements and post-test examination. Film growth rates were shown to be sensitive to both thermal-hydraulic and chemical variables.

Background and preparatory efforts were completed to allow irradiation-corrosion studies of materials for the HWR NPR. A corrosion-fatigue loop was designed and procured for use in the hot cells.

All activities related to the HWR NPR are scheduled to be terminated by the end of February 1993.

6.3 CONSERVATION MATERIALS PROGRAM — *R. A. Bradley, D. R. Johnson, H. W. Hayden, P. J. Blau, P. Angelini, P. S. Sklad, M. A. Karnitz, and T. G. Kollie*

Our materials R&D programs for energy conservation have grown significantly with DOE emphasis on increased energy efficiency and with the realization that materials are a key technology need for advanced energy conversion and utilization systems. We have established lead laboratory roles and/or major materials support tasks in the following conservation projects: (1) Ceramic Technology, (2) Transportation Materials, (3) AIC Materials, (4) Tribology, (5) Materials for Industrial Technologies, and (6) Building Materials. In the Ceramic Technology and the AIC Materials projects, we provide technical support to DOE in the planning, implementation, and management of the national DOE programs. This involves extensive interfaces and subcontracts with industry, universities, and other federal laboratories in addition to research in the M&C Division.

6.3.1 Ceramic Technology Project — *D. R. Johnson*

The CTP was initiated in FY 1983 to meet the ceramic materials technology needs of the companion DOE engine programs. The goal of the program is to establish the technology base that will allow private industry to supply reliable and cost-effective ceramics for use in advanced engines and other energy conversion applications. The program is being accomplished by using an R&D agenda developed following an extensive industrial assessment of needs that was formatted into a dynamic 5-year project plan and later revised to the complete 10-year plan. The program includes a balanced emphasis on the three technology areas recognized as necessary to achieve reliability in structural ceramics: (1) materials and processing, (2) design methodology, and (3) data base and life prediction. The R&D tasks in the program are performed in-house at ORNL, at other national laboratories, and through subcontracts with private industry and colleges and universities.

It is expected that the program goal of reliable ceramics will largely be met by the completion of the 10-year plan in 1993, a conclusion borne out by industry's successful experience in running ceramic components in engines. However, commercial implementation of the benefits of ceramic engine components is clouded by the relatively high cost of the ceramic components. Based again on extensive input from industry, the direction of the CTP is now shifting toward reducing the cost of ceramics in order to facilitate commercial introduction of ceramic components for automotive and diesel truck applications in the near term. This implies inclusion of moderate-temperature applications as well as the very high-temperature automotive gas turbine application. A systematic approach to reducing the cost of components is planned. The work elements are as follows: economic cost modeling, ceramic machining, powder synthesis, alternative forming and densification processes, yield improvement, system design studies, standards development, and testing and data base development.

6.3.2 Transportation Materials — *H. W. Hayden*

ORNL has been requested by the Office of Transportation Technology to take the lead role in initiation of two potential programs related to areas in which materials developments are critical to the implementation of advanced automotive transportation systems: Materials for Lightweight Vehicles and Materials for Electrochemical Propulsion Systems.

During 1992, a needs assessment of materials development requirements for lightweight vehicles was carried out based on numerous contacts with the three major U.S. automotive producers as well as many of the industries supplying metallic and polymeric materials to the automotive industry. On the basis of these contacts, a draft needs assessment and multiyear program plan were prepared and distributed to members of the automotive industry and their suppliers for review and comment prior to finalization. Initial efforts under the program will include a subcontract with GM Research Laboratories on advanced aluminum-forming methods, funding support for an ASME workshop on aluminum applications for transportation and industry, and funding at INEL for a joint effort with GM-Saginaw Division on instrumentation related to squeeze-casting processing.

During 1992, limited effort was devoted to the Materials for Electrochemical Propulsion Program because funding allocations for a sustained program were not in place. A review of the competing battery and fuel cell systems has been completed to establish a priority list of those systems most likely to meet automotive requirements. Toward the end of CY 1992, there were indications that funding schedules might be accelerated. As a result, a schedule for completion of a needs assessment and draft program plan by mid-1993 has been established.

6.3.3 Tribology Project — *P. J. Blau*

ORNL is responsible for the Advanced Tribomaterials and Components task area of the Office of Transportation Materials, Tribology Program. Tribomaterials are materials whose primary engineering use is for friction and wear-critical applications. The ORNL task is divided into two subtasks: tribosimulation and tribomaterials evaluation. Tribosimulation analyzes the key factors in the design of optimum, cost-effective, laboratory-scale simulations of conditions in advanced automotive and truck engines and helps establish a methodology for screening new tribomaterials. Tribomaterials evaluation identifies new materials, like ceramic composites, intermetallic compounds, and carbon-graphite materials, that have potential uses for lightweight, durable wear parts in near- and long-term advanced engines. Friction and wear tests, both lubricated and unlubricated, are conducted at various temperatures and times to establish performance limits for new materials. Extensive use of microscopy and other forms of microstructural analysis lay the groundwork for developing future low-friction, low-wear materials.

6.3.4 Advanced Industrial Concepts Program — *P. Angelini*

The Advanced Industrial Concepts Division (AICD) is part of the Office of Industrial Processes, Office of Industrial Technologies (OIT) of Conservation and Renewable Energy in DOE. The mission of AICD is to develop and maintain a balanced program of R&D focused on high-risk, long-term, directed interdisciplinary research efforts for the industrial sector in its efforts to improve energy efficiency and enhance fuel flexibility. The AIC Materials Program supports this mission, giving attention to materials engineering in the context of goals, needs, and opportunities for advanced industrial systems. The program initiates and conducts applied research and exploratory development in technical areas encompassing structural engineering materials, materials with unique (nonstructural) properties, materials processing for manufacturing, and environment-compatible materials.

6.3.4.1 ORNL AIC Materials Program — *P. S. Sklad*

Projects under the AIC Materials Program at ORNL, along with subcontracts funded through ORNL, focus on the development of a wide range of materials and processes. In the area of high-temperature intermetallic alloys (e.g., Ni_3Al, NiAl, and FeAl), work within the M&C Division has led to collaboration with industrial partners to develop heat-resistant assemblies for heat-treating furnaces, transfer rolls for heat-treating furnaces and slab-reheating furnaces used during hot processing of steel ingots, turbochargers for large diesel engines, and shape-memory alloys for use in energy and mass control applications. Other projects include continuous fiber-reinforced TiB_2 for improved Hall-Cell electrodes in the aluminum smelting industry, ultratough metal-bonded ceramics, and ceramic membrane materials for separation systems. A new effort will focus on evaluation of catalyst materials and emission control systems in order to improve manufacturing processes and performance and decrease emissions. Other activities concentrate on materials processing technology, including modeling, microwave processing of materials, surface modification of polymers, and welding development.

6.3.5 Office of Industrial Technologies — *M. A. Karnitz*

Three industrial projects are being conducted for the Industrial Energy Efficiency Division of the OIT. The objective of the first project is to provide materials technology support to develop advanced ceramic heat exchangers for industrial applications. ORNL is determining the corrosion limits of the ceramic materials and developing cost-effective methods for fabricating heat exchanger components cooperatively with several industrial suppliers and heat exchanger designers. These high-temperature heat exchangers can save significant amounts of fuel and increase productivity in the industrial processes by increasing the efficiencies of the process. Problems are resolved by using the application of current materials technology or by performing the required analysis and testing in cooperation with the industrial suppliers.

The second project for OIT is to provide assistance in the development of CFCC materials. The properties of CFCCs make them attractive in a variety of industrial applications where their use can result in energy savings and increase productivity. Ten industrial companies are developing the primary processing methods for the fabrication of CFCC components for use in industrial applications. ORNL is leading an effort to support the industrial teams by providing the scientific foundation for the successful process development and scale-up. The supporting technologies effort is being conducted by universities and national laboratories and includes the more basic or generic support task of composite design, materials characterization, test method development, and performance-related phenomena. In 1992, the emphasis was on the performance and reliability of CFCC materials.

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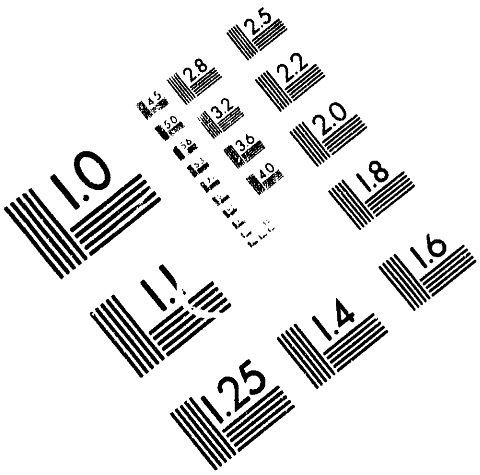

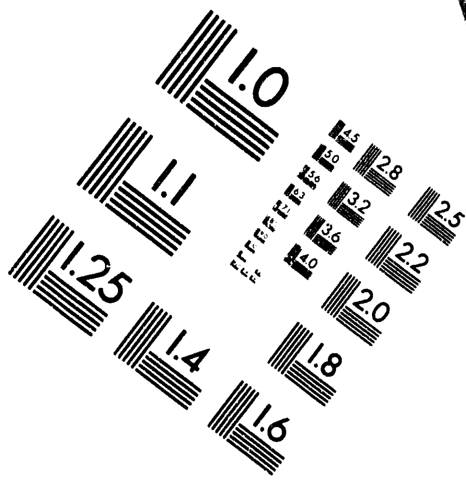

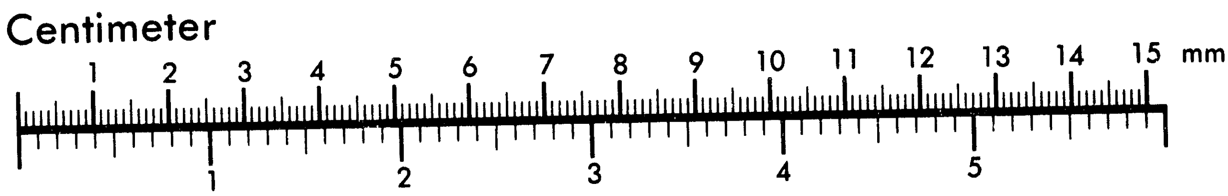

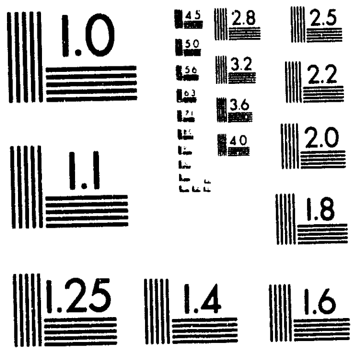

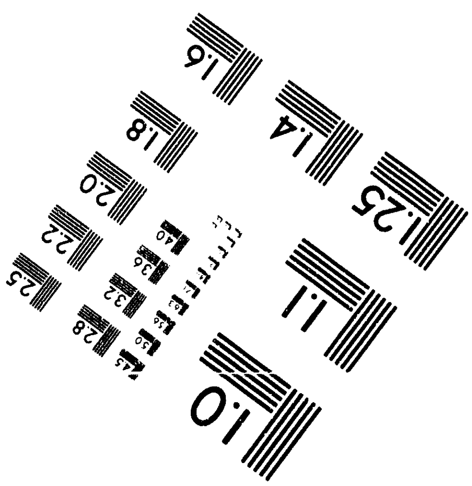

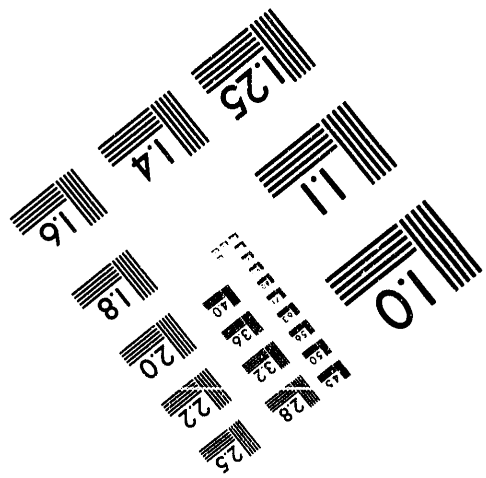

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The third project for OIT is a new program to determine the long-term survivability of ceramic materials for industrial gas turbine applications. The objective is to increase the efficiency of gas turbines used for power generation. The first element of this new program is a ceramic retrofit engine demonstration. DOE is working cooperatively with a turbine manufacturer to modify an existing engine to accept ceramic components and run a 1000-h engine test. ORNL is assisting the turbine manufacturer by performing some long-term materials testing. Existing data from many of the high-performance structural ceramics are limited to exposures of less than 2000 h. This project will extend the long-term testing to times up to 10,000 h.

6.3.6 Building Materials — *T. G. Kollie*

The objective of the Building Materials Project is to establish the technical data base for building materials that is needed to reduce the energy used for buildings. The research is developing testing techniques, new standard reference materials, analytical models for heat transfer, and alternatives for insulations containing chlorinated fluorocarbons, including new foam-blowing agents and PEPs of high thermal resistivity.

The interaction of these projects in the Conservation Materials Program with related research on the Materials Sciences and on the Fossil Energy Program at ORNL, and with research at other federal agencies and in industry, is synergistic and very productive. We anticipate continued growth in the Conservation Materials Program.

6.4 SPACE AND DEFENSE — *R. H. Cooper*

During the past year, ORNL's DOE-sponsored SNP Programs combined with activities sponsored by industry and federal agencies other than DOE have provided diverse opportunities for the application of the division's materials technologies. The status of the DOE SNP Programs and selected non-DOE-sponsored programs is discussed below.

6.4.1 DOE Space Nuclear Power Programs

Activities in support of DOE's RTG Program are the larger of the ongoing SNP Programs. In the area of RTG systems, M&C Division provides managerial oversight of activities performed throughout MMES. These activities include production of critical components for NASA's Cassini mission to Saturn scheduled for launch in 1997 and materials development.

Two primary production activities are performed at MMES. The first is the manufacture of the iridium-alloy-clad vent sets that contain the heat-generating radioisotopes used in the RTG system. This manufacturing activity requires the integration of the capabilities of ORNL and the Y-12 Plant; ORNL produces an iridium-alloy blank and foil for subsequent assembly by the Y-12 Plant into clad vent sets. In addition to the manufacture of the iridium-alloy components, the M&C staff produces CBCF thermal insulators (sleeve and disc) that minimize temperature changes at the surface of the iridium-alloy cladding during off-normal RTG operations. During 1992, the manufacture of all CBCF insulators required for the Cassini mission was completed.

Materials development activities continue to be an important task paralleling the manufacturing task. These activities include development and characterization of advanced iridium-based alloys with superior performance for the clad-vent-set or cladding application, design and qualification of a high-temperature carbon-composite material with enhanced kinetic energy absorption capabilities, and the development of cost-effective methods to refine large quantities of iridium scrap with M&C's existing EB melting facility.

For the SP-100 Project, ORNL performs a significant role in the development of the engineering data base for the refractory metals required for successful operation of a multi-100-kW(e) SNP system. The principal focus of this work is the determination of mechanical properties, characterization of irradiation effects, and evaluation of the compatibility of the refractory alloys under anticipated SP-100 system operating conditions. Further, M&C provides managerial oversight for the characterization of materials and their subsequent fabrication into large radiation-shield components, which is performed at the Y-12 Plant.

6.4.2 Non-DOE-Sponsored Programs

The Space and Defense Programs Office provides coordination of division activities supported by 35 different organizations, including industry, NASA, the EPA, Army, Navy, and Air Force. Support provided by the Space and Defense Programs Office includes administration, program development, and technical program management. Through the years, these activities have provided an important means to enhance and leverage existing materials technologies or capabilities to the mutual advantage of DOE and our non-DOE sponsors. Examples of the scope of selected activities follow.

In support of the NASA Marshall Space Flight Center, the division is determining the mechanical properties of superalloys in a high-pressure hydrogen environment. ORNL is currently conducting a round-robin test program in order to establish acceptable test methods for high-temperature, high-pressure testing in hydrogen; these test methods include tensile, fatigue, and fatigue-crack growth and will be followed by all NASA contractors.

Work is also being performed for the U.S. Air Force Wright Laboratory in optimizing and scaling-up the CVI process for the fabrication of ceramic composites for advanced man-rated turbine engine components. This work complements efforts supported by the U.S. Air Force Office of Scientific Research to evaluate the nucleation kinetics of surface films deposited by chemical vapor methods. An ORNL-developed neural network system is being utilized to analyze eddy-current patterns to meet the needs of the U.S. Air Force Wright Laboratory's NDE intelligent signal-processing program. The focus of this activity is to modify the neural network codes as well as the data acquisition and reduction processes to increase execution speed and enhance signature recognition performance generated by selected NDE applications. An additional activity is being performed for the U.S. Air Force Engineering Services Center. In this activity, CT scanning images of samples of typical asphaltic concrete used in airfield pavements were generated and evaluated to provide information to be used for U.S. Air Force engineering modeling studies.

Three new Navy projects were initiated in 1992. A project aimed at gaining a fundamental understanding of the development and distribution of residual stresses in welds was begun for the ONR. Research on the nature of crack initiation and growth in ceramic deep-submergence vessels, utilizing alumina ceramics manufactured by WESGO and Coors Ceramics, is being performed for the Naval Command, Control, and Ocean Surveillance Center, RDT&E Division. A project was begun for the Naval Air Warfare Center to perform specific research on the development of SiC-reinforced Si_3N_4 matrix composites currently being developed under Navy sponsorship at Allied Signal Research and Technology. These coatings will be used to improve the environmental stability and mechanical properties of the Allied Signal composite systems.

6.5 FOSSIL ENERGY PROGRAM — *R. R. Judkins*

The ORNL Fossil Energy Program Office, located in the M&C Division, manages research activities within the division and in several other divisions within ORNL. The focus of ORNL's Fossil Energy Program is on materials R&D, ES&H activities, bioprocessing of coal, coal combustion research, and modeling activities on the operational requirements of the Strategic Petroleum Reserve.

6.5.1 FOSSIL ENERGY MATERIALS PROGRAM — *N. C. Cole*

The ORNL FEMP Office is a part of the M&C Division, and it is from this office that the activities of the program, within the M&C Division and at other federal and industrial laboratories and universities, are managed. Virtually all the materials research on the program within ORNL is performed in the M&C Division. The focused materials R&D covers research on ceramics, new alloys, and the mechanisms of erosion and corrosion. Transfer to industry of the technology covering the knowledge, materials processes, and procedures generated is an important activity of the program. Ceramic composites and new alloys are being examined for filtration and structural applications. Advanced ceramic membranes are being developed for hydrogen and other gas separation. Materials technical support and failure analyses are provided to projects on the Clean Coal Technology Program. A major function of the FEMP is management (with DOE-OR) of the Fossil Energy AR&TD Materials Program. Fiber-reinforced ceramic composites with improved strength and toughness are being produced by a special forced chemical vapor infiltration and deposition (FCVID) process developed at ORNL. With the forced-flow, temperature gradient of the ORNL process, thicker material can be produced, whether it be plate or tubing. Thicker SiC composites have potential application as tubing and headers in high-temperature heat exchangers. Control of the interface between the fiber and matrix in composites allows greater toughness through fiber pullout during fracture. The ability to control the porosity of these ceramic composites through the FCVID process means that both highly dense (for structural purposes) as well as porous composites (for hot-gas cleanup filters) can be fabricated.

Ceramic membranes for the separation of gases in high-temperature and hostile environments are being developed and tested. Investigators at the Oak Ridge K-25 Site have produced ceramic (alumina) membranes with mean pore diameters of about 10 Å, a size close to the pore size necessary for hydrogen separation. Membranes have already been fabricated and successfully tested for their permeability to nitrogen, helium, and carbon dioxide at room temperature in the pressure range of 15 to 150 psi. A CRADA is being negotiated to transfer some of that technology to a company with the proper clearances.

The sintering of ceramics with microwave energy is being explored. ORNL has developed the ability to sinter certain ceramics to high densities. Basic studies have been conducted to provide us with an understanding of the microwave sintering phenomenon. The present hypothesis is that the magnitude of the so-called "microwave effect" for a material is proportional to the ionic conductivity of that material. This technology could be important in the fabrication of electrode and electrolyte materials with improved electrical properties for solid oxide fuel cells. Microwaves are being explored as a heating source during the FCVID process.

ORNL has been developing advanced austenitic alloys for use in fluidized-bed and advanced steam cycle coal combustion power plants. The objective of this work is to modify existing alloys and develop new alloys that will satisfy the strength and corrosion-resistance requirements of high-temperature and high-pressure, second-generation power plants. The modified 800 alloys and the lean austenitic stainless steels (termed "lean" because of their lower-than-usual content of the strategic metal chromium) are high-strength steels developed for high-temperature applications typical of those in fossil power environments. The high-temperature creep life of these alloys is several orders of magnitude greater than that of conventional alloys. It has been demonstrated that the ORNL-developed modified 800 and 316 advanced austenitics can be fabricated with commercial equipment, and many compositions are weldable. Due to their exceptionally high creep strength at 500 to 750°C, higher strength welding filler metals have been explored. Transfer of this technology to industry is under way. Also, current materials and designs for tubesheet and manifolds for hot-gas filter systems have been examined to recommend a tubesheet material suitable for long-term operation of these systems.

Intermetallic alloys based on Fe_3Al are being developed for applications in which superior oxidation and sulfidation resistance and strength are required. The iron aluminides are intermetallic compounds that for several years have been known for numerous outstanding properties, but their brittleness at ambient temperatures precluded many applications. Alloy modifications and special heat treatments developed at ORNL have produced tensile ductilities of over 15% at room temperature. Several compositions are weldable with the use of preheat and postweld heat treatments as is often needed with other high-strength materials. Uses of these alloys as coatings and claddings are also being explored. A new chromium-niobium (Cr-Nb) intermetallic alloy is under development. It shows promise of extremely high strength at high temperatures and may be a metallic alternative to certain ceramics.

Basic studies of erosion and corrosion have been conducted to develop a fundamental understanding of these processes and their relationship to materials properties. Corrosion research in the M&C Division centers on studies of the formation and breakdown of protective oxide scales, particularly in sulfur-containing atmospheres, and on the effect of environment on corrosion and mechanical properties of iron aluminides and Cr-Nb.

Assessments of materials problems and of the needed research to solve those problems for a variety of fossil energy technologies are an important part of ORNL's materials effort. Materials failure analyses, a significant factor in the success of advanced clean coal technologies, continue to be conducted for the Pittsburgh Energy Technology Center. Similar technical support is provided to operators of coal conversion and utilization plants in the identification of, and solutions for, materials problems.

ORNL has a commitment to transfer the technology developed on the FEMP to industry and to others in the fossil energy community. Licensing agreements have been signed with three industrial firms for the ORNL-developed iron aluminides technology. One agreement is with Ametek Specialty Metal Products Division for the purpose of producing Fe_3Al powders. Licenses for other product forms have been awarded to Harrison Alloys and to Hoskins Manufacturing Company. An option license agreement on the Fe_3Al technology was signed with Castmasters, Inc., of Bowling Green, Ohio. Work was done on a CRADA between 3M and ORNL for work on an SiC filter process. CRADAs are under negotiation with industry on iron aluminides, advanced austenitics, and ceramic composites.

6.6 FUSION ENERGY MATERIALS PROGRAM — *E. E. Bloom*

The Fusion Energy Materials Program has three major points of focus: (1) development of reactor structural materials, (2) development of first-wall and high-heat-flux materials, and (3) development of ceramics for electrical applications. Within the Office of Fusion Energy, these efforts are supported by the neutron interactive materials and the plasma interactive materials programs. The ORNL effort supports U.S. participation in the ITER as well as the ultimate objective of making fusion an economically competitive and environmentally attractive energy source.

In the structural materials program, the primary emphasis remains on qualification of austenitic stainless steels for ITER and the development of low-activation ferritic steels, vanadium alloys, and ceramic composites (e.g., SiC/SiC).

Austenitic steels are the leading candidate for structural applications in ITER because of their advanced state of development and commercial practice. In a collaborative program with the JAERI, we are investigating the effects of fusion reactor radiation damage levels on the engineering properties of these alloys. Central to this effort is the irradiation of these alloys in the HFIR with tailoring of the neutron spectrum to produce damage levels (i.e., transmutation-produced helium and dpa) equivalent to those produced in a fusion reactor spectrum. These experiments are providing data and understanding of radiation response at temperatures and damage levels that are precisely those required for the ITER Engineering Design Activity (i.e., 60 to 400°C, up to 30 dpa).

Development of low- or reduced-activation materials is critical to achieving fusion's potential as a safe and environmentally attractive energy source. Development of low-activation ferritic steels requires that metallurgically important elements such as Ni, Mo, Nb, and N be removed or reduced to relatively low levels and that potential impurity elements be controlled to acceptable levels. To develop low-activation martensitic steels, tungsten is being used as a substitute for molybdenum, and niobium is replaced by tantalum and vanadium. The development activities are focused on the most critical or limiting property of this class of alloys—the radiation-induced shift in DBTT and reduction of fracture toughness. The vanadium alloys that are being considered for fusion have attractive activation characteristics, so compositional modification is not required to achieve this goal. The focus of our research on vanadium alloys is chemical compatibility with proposed fusion coolants and the effects of irradiation on fracture toughness. From the viewpoint of induced activation, SiC is the ultimate fusion structural material. Monolithic SiC is not considered because of its fracture properties. SiC/SiC composites offer an approach to improved fracture toughness. Our understanding of the performance of these materials in an irradiation environment is extremely limited. The focus of our present research is to explore the effects of irradiation on properties so as to provide a basis for accurately assessing the potential of SiC/SiC composites as fusion structural materials and to begin efforts to tailor these materials for the fusion environment.

The effects of irradiation on the dielectric properties of ceramic insulators are of critical importance in the successful design and operation of numerous systems in a fusion reactor (e.g., RF heating and plasma diagnostics). Our initial experimental work (initiated in 1991) has been directed at in situ measurements of the loss tangent during ionizing and ionizing-plus-displacive irradiation. Results to date show an increase in loss tangent of nearly two orders of magnitude at a displacement rate of $\sim 10^{-7}$ dpa/s. A change of this magnitude will impact materials selection and design of RF heating systems for ITER. Measurement of in situ properties will be expanded to investigate radiation-enhanced dielectric breakdown and the effects of irradiation on structural evolution and mechanical properties.

Graphite and C/C research activities are part of the plasma interactive and high-heat-flux materials programs. Graphite and C/C composite materials are selected for these applications because their low Z number minimizes radiative heat losses from the plasma. However, their application requires graphite and C/C composites with extremely good thermal shock, erosion, and neutron damage resistance. Optimum thermal shock resistance is assumed to be offered by appropriately designed C/C composites (i.e., selected fibers, matrices, and architectures). Current work is directed toward the optimization of these materials for neutron-damage resistance.

6.7 DP TECHNOLOGY TRANSFER INITIATIVE — *P. Angelini*

The DP Technology Transfer Initiative is based on the dual-use concept of enhancing the competitiveness of U.S. industry and the capabilities of the DP activities. There are five main focus areas in the technology initiative including materials and materials processing, manufacturing, energy and environment, microelectronics and photonics, and computing. During this past year, proposals have been submitted in two calls for proposals. The initiative utilizes the CRADA mechanism that enables close cooperation between the industrial partner(s) and MMES. Typically, there are two opportunities per year to submit joint proposals. The proposals contain strong industrial components, tasks, and commitments of in-kind funding and are focused on technical issues driven by the industrial partners. Work that has been successfully funded and initiated relates to materials, materials process development, materials and process modeling, and computing.

7. COLLABORATIVE RESEARCH FACILITIES AND TECHNOLOGY TRANSFER

7.1 ORNL/ORAU SHARED RESEARCH EQUIPMENT PROGRAM (SHaRE) — *E. A. Kenik and N. D. Evans*

The SHaRE Program allows participants from universities, industries, and other national laboratories access to the wide range of often unique microanalytical facilities within the M&C Division. The program is aimed at collaborative research in materials science in areas pertinent to the U.S. DOE and the ORNL mission and emphasizes areas under current investigation within the M&C Division. Facilities and techniques included under the SHaRE Program are analytical and intermediate-voltage electron microscopy, APFIM, Auger electron spectroscopy, nuclear microanalysis, XRD, ion implantation, and mechanical properties microanalysis. A number of SHaRE projects complement the advanced materials development programs in the M&C Division, such as advanced ceramics, ordered intermetallics, radiation effects, and austenitic alloys.

During this period, the Division of Materials Sciences, Office of BES, provided funds through Oak Ridge Associated Universities (ORAU) to support the SHaRE activity. Program funds are used for travel and living expenses for university SHaRE participants while at ORNL and for the support of Neal Evans, a liaison between M&C Division research staff and the SHaRE participants. His principal responsibilities included participation in SHaRE research when appropriate and familiarizing SHaRE participants with the electron microscope and computer facilities. His presence has allowed a high level of SHaRE participation with minimal interference with ORNL in-house programs.

A steering committee reviews all proposed SHaRE projects and defines SHaRE Program policy. The members in FY 1992 were: E. A. Kenik, ORNL; J. Bentley, ORNL; M. G. Burke, Westinghouse Science and Technology Center; B. Fabes, University of Arizona; N. D. Evans, ORAU; and R. Wiesehuegel, ORAU.

During this reporting period, 22 of 27 approved SHaRE projects were active; five of the active projects did not require travel support. The active projects involved 41 outside participants (users), including 20 students. At least 23 papers based on SHaRE research were published in the past 12 months, and approximately 18 presentations have been made at technical meetings. Currently, another 14 papers based on SHaRE research have been accepted for publication or are in press. Furthermore, this was a very fruitful period for the SHaRE Program in terms of graduate students whose participation in the program benefited their recently completed dissertation studies. Two Master of Science and four Doctor of Philosophy degrees were completed. Additionally, 15 more graduate students are progressing in their dissertation studies by participating in the SHaRE Program.

7.2 ORNL/ORAU SYNCHROTRON ORGANIZATION FOR ADVANCED RESEARCH — *C. J. Sparks*

The M&C Division X-Ray Group, in collaboration with the Materials Research Laboratory at the University of Illinois, operates an intense X-ray beamline on the NSLS to study the crystallographic structure of weakly scattering materials. This beamline is open to outside users for qualified experiments. During this past year, more than 20 different experiments were performed by 63 scientists from 6 different universities, 2 industrial, and

2 government laboratories with 20 published papers, including 4 *Physical Review Letters* with 1 Ph.D. thesis. A major advantage of the beamline is the ability to select an X-ray energy near an absorption edge of a specific element. This changes the X-ray scattering cross section of the element and highlights the atom to help reveal its crystallographic symmetry site. In this way, we are able to determine crystallographic sites at which substitution takes place. Among the uses made of this chemical sensitivity were studies of atomic positions at buried interfaces, substitution of a third element in binary ordered intermetallics, and local arrangements in amorphous and crystalline solutions. Other research during this report period included the study of C_{60} molecules to encapsulate a surface. Since C_{60} is chemically inert, delicate surface structures might be preserved outside ultrahigh vacuums under this coating even when exposed to ambient conditions for transportation. Surface structures of silicon were preserved under this C_{60} inert cap; however, a Cs-doped Ag(110) surface, which normally undergoes the (2×1) reconstruction, is suppressed. Inelastic X-ray scattering spectroscopy has shown that the electronic structure of undoped C_{60} crystals gives rise to an interbond transition at an energy loss of 80.1 aJ (5 eV) and a plasmon loss of 432.5 aJ (27 eV). These losses differ from that of C_{60} gas and graphite and will be used as a baseline in the study of the effects of doping C_{60}. Studies of pure acid and alcohol monolayers show identical high-pressure structures. For lower pressures, the structures differ. XRD studies have now shown that near-neighbor tilt seen in acid monolayers explains their different responses to compression.

7.3 TECHNOLOGY TRANSFER — *J. R. Weir, Jr.*

Substantive activities this year involved providing technical assistance to current and potential licensees, conducting one technology transfer meeting, successfully negotiating six new licenses, negotiating collaborations to further develop ORNL technologies, and providing information on technologies through oral presentations and written communication.

To date, the 29 licensees to the M&C Division technologies are:

1. Advanced Innovative Technologies*; American Matrix; Advanced Composite Materials; Cercom, Inc.; Dow Chemical; GTE; Hertel; High Velocity; Inland Industries*; Iscar; Kennametal; and Keramont Corporation (SiC whisker-reinforced ceramics);

2. Instron (ceramic gripper assembly for tensile testing);

3. Ametek; Armada Corporation (Hoskins); Armco, Inc.; Cummins Engine; Harrison Alloys; Metallamics; and Valley Todeco (Ni_3Al alloys);

4. 3M (novel ternary ceramic alloy);

5. Coors Ceramics (gelcasting method of making complex ceramic shapes);

6. Ametek; Cast Masters*; Harrison Alloys; and Hoskins Manufacturing Company (iron aluminides);

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*Licenses signed in FY 1992.

7. Microscience (atom probe software/field ion microscope);

8. Sigma Tech* (ultralight electromagnetic shielding); and

9. Microwave Laboratories* (variable-frequency microwave furnace).

Of the royalties from licenses of MMES technologies in FY 1992, 58% were from M&C Division patents.

A technology transfer meeting on nickel and iron aluminides was held on August 4-5, 1992. The attendance at this meeting was restricted to the licensees and those organizations that had shown substantial interest in the technologies. Approximately 25 representatives attended.

The ASM International Technology Transfer Committee (chaired by a staff member) consists of 22 members of federal and national laboratories.

Following is the status of CRADAs in the M&C Division:

Client	Technology	CRADA approved
Eaton & Johnson Controls	Shape Memory Alloy	06/13/91
Garrett (Allied Signal)	Microwave Annealing of SiN with High Additive Content	08/22/91
Norton Company	Microwave-Sintered Reaction-Bonded SiN	09/05/91
Norton Company	Microwave Annealing of SiN with Low Additive Content	9/05/91
Appliance Research Consortium	Powder-Evacuated Panel	07/22/91
Microwave Labs	Wideband Microwave Processing Equipment	11/04/91
AVX Tantalum Corporation	Microwave-Sintering Tantalum Capacitors	11/04/91
3M Company	Chemical Vapor Infiltration of Ceramic Composites	02/03/92
General Motors	Alloy Heat-Treating Furnaces	02/03/92

*Licenses signed in FY 1992.

Client	Technology	CRADA approved
Coors Ceramics	Machining and Inspection of Ceramics	02/18/92
PPG Industries	Powder-Evacuated Panel	06/24/92
Detroit Diesel	Machining Ceramics	08/26/92
Coors Ceramics	Gelcasting Ceramics	09/28/92
Metallamics	Nickel Aluminide Rolls	09/28/92
General Motors	Lightweight Materials	09/28/92
Norton/TRW	Machining Ceramics	In progress

Thirteen invited technology transfer presentations were made describing 20 M&C Division technologies. The technology transfer exhibit was shown at seven meetings. We responded to over 100 inquiries for information and sample materials.

A state outreach initiative has been funded in FY 1993 to utilize the technology transfer concepts developed in a previously funded DOE project called the University-Laboratory-Industry Technology Brokerage System. The project will involve visits to two selected states to present seminars and workshops to state economics development and community college officials to develop state networks to access the technology at federal laboratories on behalf of small companies.

8. EDUCATIONAL PROGRAMS

L. L. Horton

M&C Division's involvement in educational activities continues to grow. In FY 1992, there were more than 100 "paid" guests (~17 professors, 6 high school teachers, over 60 graduate/undergraduate students, and ~23 postdoctoral fellows) in the division. These personnel are brought into the division by a host of programs coordinated by ORISE and the Southeastern University Research Association, by the ORNL co-op program, and under university and personal services subcontracts. In addition, ~2,800 pre-collegiate students and over 425 pre-college teachers participated in programs sponsored or co-sponsored by M&C. The involvement with these students ranged from on-site tours to hands-on research experiences for pre-college students and teachers.

About 400 pre-college students and over 150 teachers actually toured division facilities. These tours included presentations about materials science and hands-on demonstrations of electron microscopy, ceramic processing, and superconductivity.

Three years ago, our pre-college education programs began with the establishment of a "Fun with Materials" presentation. Mike O'Hern, our main presenter, is now with Nanoinstruments, Inc., but continues to give these presentations at local schools under subcontract. M&C provides all of the necessary supplies and equipment, including the aluminum disks presented to each student. A slide show, "The Microscopic World," has also been developed for in-school and auditorium presentations. School outreach programs involved over 1,500 students and 125 teachers.

M&C Division was involved with several other major educational outreach programs including "Science in Action," the ORNL National Science Foundation (NSF) National Teacher Enhancement Workshop on Materials, the DOE-Appalachian Regional Honors Workshop, the National Educators' Workshop (NEW), and the National Junior Science and Humanities Symposium. The Science in Action Program is a three-day, multi-disciplinary program held during Engineer's Week in February. It is affiliated with the WATTeC conference and involves local technical and professional societies. M&C Division provides one of the co-chairmen and several of the speakers and exhibits. Over 550 students and over 70 teachers participated. M&C-sponsored presentations included "Fun with Materials" and "What is a Scientist/Engineer?" as well as exhibits on microscopy.

The 1992 ORNL-NSF Teacher Enhancement Workshop focused on materials science. This is the third year of M&C Division involvement with this program. We presented over two days of presentations, interactive demonstrations, and tours to 50 elementary and middle school teachers. We also gave a half-day presentation/tour program for 75 high school teachers as part of the University of Tennessee Academy for Teachers of Science and Mathematics.

M&C Division was the host for the NEW on Standard Experiments in Engineering, Materials Science, and Technology. The NEW is a 3-day workshop for educators from colleges, junior colleges, and universities. In the November 1991 workshop, Jim Stiegler was the co-chair. M&C also provided the local organization, tours of the division facilities, and gave key presentations on structural ceramics, terminology for experiments and testing, accessing national laboratories for research and educational equipment, and microscopy demonstrations for pre-college students.

M&C staff are also involved in outreach activities focussed on women students. We participate in the ORNL Women in Science Program for college-age and pre-college women (presentations and tours) and in the "Sharing Adventures in Engineering and Science" Program for middle school girls (off site presentations).

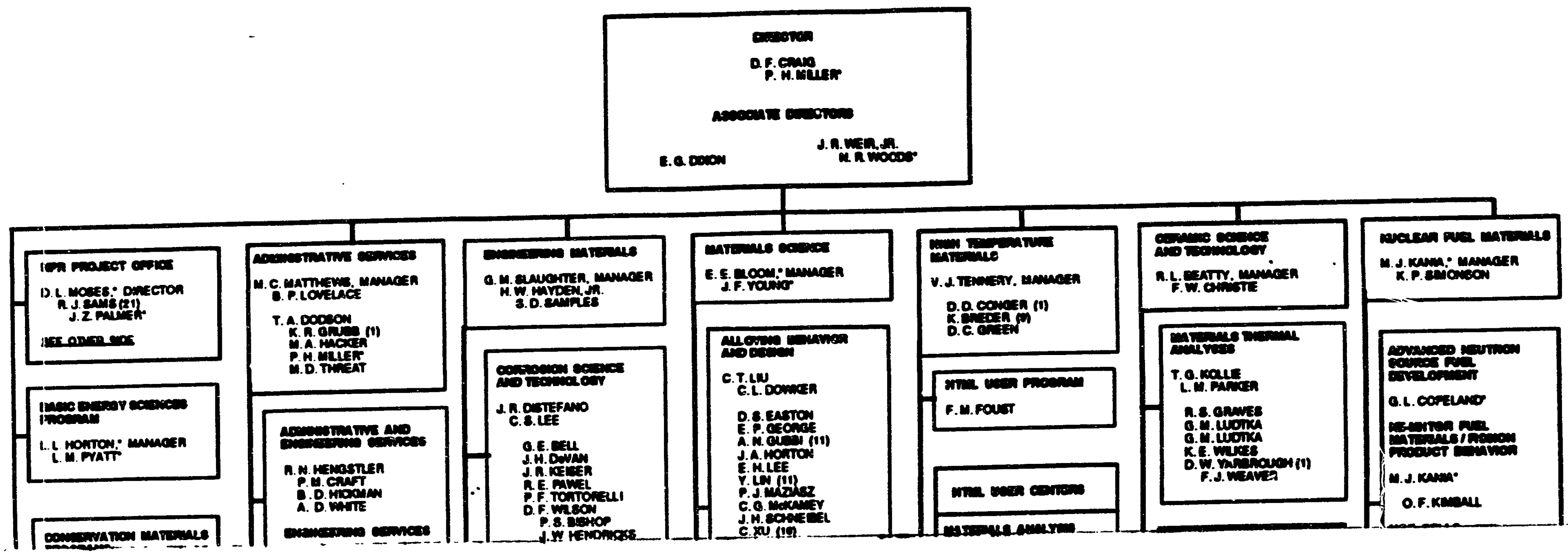
Our largest, single effort for this year was the ORNL High School Honors Workshop, co-sponsored by DOE and the Appalachian Regional Commission. The Honors Workshop, co-hosted by M&C and Environmental Sciences Divisions, was a 2-week research experience for 110 high school students and 9 teachers. The student activities included research projects, theme sessions focussed on materials-environmental issues, and diverse social activities. During the second week of the program, the students wrote a short report of their research and gave an oral presentation of their results. The group was divided into 25 research teams; the 13 research topics in M&C were:

- Study of the Fracture Properties of Two Steels
- Advanced Ceramics: Being Tough for Tomorrow
- Reactor Fuel
- Growth and Characterization of Thin Films
- Alloys: Their Manufacturing and Testing
- Microwave Processing of Ceramics
- Weldability Testing for Hot-Cracking of Stainless Steel and Al-Li Alloys
- High Critical Temperature Superconductors: Synthesis, Processing, and Characterization
- Investigation of Tensile Properties of Various Metals and Alloys
- The Microscopic World: Characterization of Ceramics Using Various Microscopy Techniques
- Exploring the Nature of the Chemical Bond: Computing the Structure of Atoms and Molecules
- Damage-Tolerant Ceramics
- Comparative Analysis of Intergranular Stress-Corrosion Cracking in Selected Steel Alloys

Appendix A

METALS AND CERAMICS DIVISION

OCTOBER 1, 1982



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V. T. JENKINS

CERAMIC MANUFACTURABILITY

T. O. MORRIS (9)

L. J. O'ROURKE (9)
R. J. PARTEN
J. E. SHELTON

METALLOGRAPHY

J. R. MAYOTTE
B. F. BYRUM*

M. J. GARDNER
T. S. GEER
H. F. LONGMIRE
A. M. WILLIAMS

ORNL/UT DISTINGUISHED SCIENTIST

D. C. JOY

TECHNICAL PHOTOGRAPHY

J. W. NAVE
B. F. BYRUM*

C. L. ANGEL
K. A. CHOUDHURY
J. D. FORD, JR. (3)
J. D. SMITH (3)

[illegible]

W. H. BUTLER

CARBON MATERIALS TECHNOLOGY

T. D. BURCHELL
J. I. KELLY

E. L. FULLER, JR.
O. C. KOPP (1)
D. F. PEDRAZA
J. M. ROBBINS
G. R. ROMANOSKI
L. L. SNEAD*
J. P. STRIZAK*
C. E. WEAVER
J. L. BAILEY
D. L. BARKER
B. R. CHILCOAT
G. E. NELSON
M. R. ROGERS

CERAMIC PROCESSING

A. E. PASTO
B. J. RUSSELL

M. A. JANNEY
J. O. KIGGANS, JR.
H. D. KIMREY
R. J. LAUF
A. J. MOORHEAD
S. D. NUNN
O. O. OMATETE
T. N. TIEGS
C. C. DAVISSON
W. H. ELLIOTT, JR.
P. J. JONES
P. A. MENCHHOFER
C. A. WALLS

CERAMIC SURFACE SYSTEMS

T. M. BESMANN
J. R. LOWE

P. J. BLAU
W. Y. LEE
R. A. LOWDEN
J. C. McLAUGHLIN
D. P. STINTON
D. M. WALUKAS (12)
C. S. YUST
M. C. CLARK
K. M. COOLEY
R. L. JACKSON
H. R. LIVESEY*
J. H. MILLER (1)

STRUCTURAL CERAMICS

P. F. BECHER
V. M. GIBSON

K. B. ALEXANDER
A. BLEIER
G. C.-H. HSUEH
H. T. LIN
S. B. WATERS*
C. G. WESTMORELAND
W. H. WARWICK

KEY

REVITALIZATION PROGRAM

P. E. ARAKAWA

J. D. LENTZ

ADVANCED FUEL APPLICATIONS

M. J. KANIA*

R. D. TAYLOR*

HIGH TEMPERATURE FUEL BEHAVIOR

W. A. GABBARD
P. D. HIGHES (1)

C. M. MALONE
R. N. MORRIS
M. F. OSBORNE (1,7)
J. R. TRAVIS (1,7)

IRRADIATED FUELS EXAMINATION LABORATORY

C. E. DeVORE
G. N. WORLEY*

T. M. KENNEY
M. PAYNE
J. L. WRIGHT
D. L. BYRUM
S. D. CHILDS
P. D. HOWARD
J. A. PATTY

FUEL MATERIALS EVALUATION

N. H. PACKAN
G. N. WORLEY*

C. A. BALDWIN
L. G. SHRADER
R. D. TAYLOR*
C. W. BOGGS
W. S. EATHERLY

FUEL MATERIALS TESTING

J. T. PARKS
J. R. HENDRICKS (1)

G. L. BELL
G. L. COPELAND*
L. C. EMERSON

FUEL PERFORMANCE MODELING

M. J. KANIA*
J. R. HENDRICKS (1)

R. C. MARTIN
B. F. MYERS

PROGRAM
E. E. BLOOM,* MANAGER
J. F. YOUNG*

REACTOR MATERIALS PROGRAMS
P. L. RITTENHOUSE, MANAGER
M. A. COLLINS

HPR FUELS PERFORMANCE
O. M. STANSFIELD
C. L. CHEVERTON*

STRUCTURAL MATERIALS
D. O. HOBSON
C. L. CHEVERTON*

SPACE AND DEFENSE PROGRAMS
R. H. COOPER, JR., MANAGER
D. L. MORRIS

J. P. MOORE*

SPACE REACTOR TECHNOLOGIES PROGRAM
J. P. MOORE*

SPECIAL APPLICATIONS
M. M. MARTIN
M. C. LAMB

WORK-FOR-OTHERS PROGRAM
R. T. KING
T. C. REUTHER (19)
S. G. FRYKMAN

QUALITY PLANNING AND CONTROL
J. S. IVEY (8)

QUALITY ASSURANCE SPECIALIST (QAS)
M. C. VANCE (8)
N. R. WOODS*

CONTROL
C. A. MAPLES

FACILITY COORDINATOR
C. W. HOUCK

M. D. GOLDEN (4)
S. H. WEBBER (4)

FINANCE OFFICE
D. L. SLAGLE (2)
A. J. CARTER

(untitled)
V. K. SIKKA
M. L. ATCHLEY

K. S. BLAKELY
C. E. DUNN
R. L. HEESTAND
T. J. HUXFORD
E. K. OHRINER
T. K. ROCHE
S. VISWANATHAN
D. C. HARPER
E. C. HATFIELD
C. R. HOWELL
J. D. VOUGHT

MECHANICAL PROPERTIES
C. R. BRINKMAN
J. B. BOZEMAN

J. L. DING (17)
L. K. EGNER
B. GIESEKE
J. A. HORAK
K. C. LIU
H. E. McCOY, JR.
H. PIH (1)
R. W. SWINDEMAN
R. H. BALDWIN
B. L. P. KEYES
T. P. KIRKLAND
C. O. STEVENS
H. D. UPTON

NONDESTRUCTIVE TESTING
D. J. McGUIRE
H. D. ROBINSON

D. R. CHILDRESS
L. D. CHITWOOD
K. V. COOK
C. V. DODD
B. E. FOSTER
W. A. SIMPSON, JR.

SPECIAL PROJECTS
J. T. HUTTON (5)

R. D. GODFREY*

J. BENTLEY
N. D. EVANS (10)
A. T. FISHER*
R. JAYARAM (9)
D. L. JOSLIN (12)
E. A. KENIK*
B. N. LUCAS (12)
M. K. MILLER
W. C. OLIVER (1)
J. M. VITEK
Z. L. WANG (9)

RESEARCH SUPPORT GROUP
A. T. FISHER*
R. D. GODFREY*

K. F. RUSSELL
J. M. COLE
J. W. JONES

STRUCTURAL MATERIALS
A. F. ROWCLIFFE
G. L. BURN

L. T. GIBSON
M. L. GROSSBECK
Y. KATANO (15)
R. L. KLUEH
J. E. PAWEL
K. SHIBA (15)
L. L. SNEAD*
C. A. WANG (11)
D. P. WHITE (9)
R. YAMADA (15)
S. J. ZINKLE
N. H. ROUSE

SUPERCONDUCTING MATERIALS
D. M. KROEGER
G. M. SIMS

A. GOYAL (9)
F. A. LIST III
D. D. PAUL (13)
R. K. WILLIAMS
P. M. MARTIN

ORNL/UT DISTINGUISHED SCIENTIST
D. C. JOY

TECHNICAL PHOTOGRAPHY
J. W. NAVE
B. F. BYRUM*

C. L. ANGEL
K. A. CHOUDHURY
J. D. FORD, JR. (3)
J. D. SMITH (3)

THEORY
W. H. BUTLER
B. E. MERCER

C.-L. FU
R. G. JORDAN (18)
Y. LIU (10)
D. M. NICHOLSON
G. S. PAINTER
G. M. STOCKS
X.-ZHANG (14)

X-RAY RESEARCH AND APPLICATION
C. J. SPARKS, JR.*
L. M. PYATT*

R. E. CLAUSING
L. HEATHERLY
G. E. ICE
R. A. McKEE
J. L. ROBERTSON (22)
E. D. SPECHT
F. J. WALKER (9)
P. ZSCHACK (10,18)

STRUCTURAL CERAMICS
P. F. BECHER
V. M. GIBSON

K. B. ALEXANDER
A. BLEIER
G. C.-H. HSUEH
H. T. LIN
S. B. WATERS*
C. G. WESTMORELAND
W. H. WARWICK

FUEL MATERIALS TESTING
J. T. PARKS
J. R. HENDRICKS (1)

G. L. BELL
G. L. COPELAND*
L. C. EMERSON

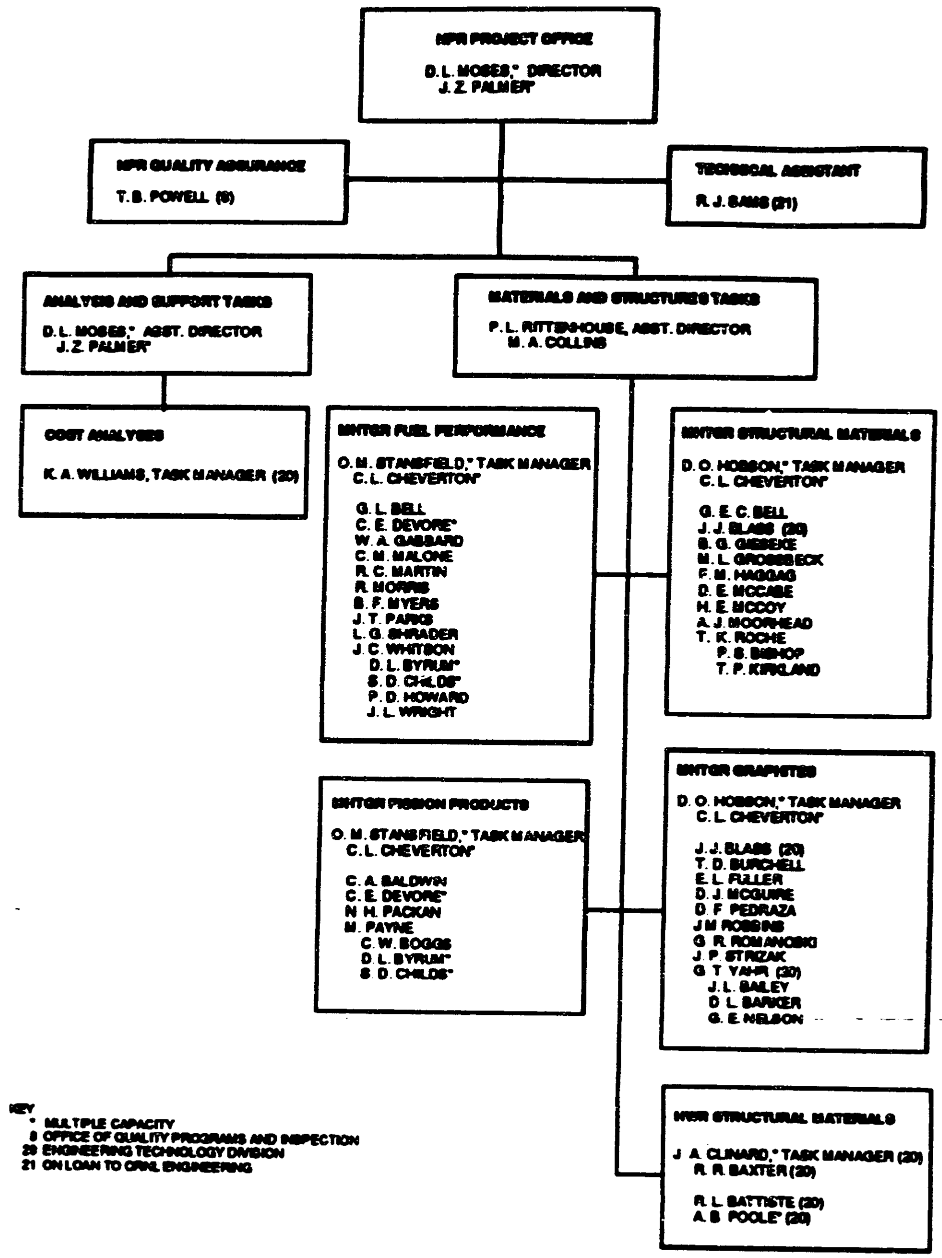
FUEL PERFORMANCE MODELING
M. J. KANIA*
J. R. HENDRICKS (1)

R. C. MARTIN
B. F. MYERS

KEY
* MULTIPLE CAPACITY
1 PART TIME
2 FINANCE AND BUSINESS MANAGEMENT DIVISION
3 GRAPHICS DIVISION
4 PLANT AND EQUIPMENT DIVISION
5 INSTRUMENTATION AND CONTROLS DIVISION
6 Y-12 DEVELOPMENT DIVISION
7 CHEMICAL TECHNOLOGY DIVISION
8 OFFICE OF QUALITY PROGRAMS AND INSPECTION
9 POSTDOCTORAL FELLOW
10 OAK RIDGE INSTITUTE FOR SCIENCE AND EDUCATION
11 GUEST, AUBURN UNIVERSITY
12 GUEST, UNIVERSITY OF TENNESSEE, KNOXVILLE
13 GUEST, TENNESSEE TECHNOLOGICAL UNIVERSITY
14 GUEST, UNIVERSITY OF KENTUCKY
15 GUEST, JAPAN ATOMIC ENERGY RESEARCH INSTITUTE, JAPAN
16 GUEST, FLORIDA ATLANTIC, BOCA RATON
17 GUEST, WASHINGTON STATE UNIVERSITY
18 ON ASSIGNMENT TO NATIONAL SYNCHROTRON LIGHT SOURCE, BROOKHAVEN NATIONAL LABORATORY
19 ON ASSIGNMENT TO THE ORNL WASHINGTON OFFICE
20 ENGINEERING TECHNOLOGY DIVISION
21 ON LOAN TO ORNL ENGINEERING
22 GUEST, SANDIA NATIONAL LABORATORIES, LIVERMORE

DIVISION COMPUTER SECURITY OFFICER – D. J. WALMSLEY*
DIVISION EMERGENCY DIRECTOR – J. P. STRIZAK*
DIVISION PRECIOUS METALS COORDINATOR – J. K. BAIN*
SPECIAL NUCLEAR MATERIALS CONTROL – C. W. HOUCK*

* METALS AND CERAMICS DIVISION
OCTOBER 1, [illegible]
PAGE 2



Appendix B

PERSONNEL SUMMARY

October 1, 1991, to December 31, 1992

Compiled by Barbara Lovelace

New Staff Members

A. Scientific Staff

G. L. Bell	Fuel Materials Testing Group
W. Y. Lee	Ceramic Surface Systems Group
J. D. Lentz	Hot Cells Revitalization Program Group
H. T. Lin	Structural Ceramics Group
S. D. Nunn	Ceramic Processing Group
A. E. Pasto	Ceramic Processing Group
L. L. Snead	Carbon Materials Technology Group
S. Viswanathan	Materials Processing Group
A. A. Wereszczak	Mechanical Properties Users Group

B. Administrative and Technical Support Staff

J. E. Bozeman	Mechanical Properties Group
P. M. Craft	Administrative and Engineering Services Group
R. D. Godfrey	Microscopy and Microanalytical Sciences Group
C. E. Hempfling	Communications and Records Support Services Group
L. M. Kendrick	Communications and Records Support Services Group
M. C. Lamb	Space and Defense Programs Special Applications Office
J. R. Lowe	Ceramic Surface Systems Group
P. M. Martin	Superconducting Materials Group
L. M. Parker	Materials Thermal Analyses Group

Staff Transfers and Terminations

A. Scientific Staff

D. N. Braski	Transferred from Y-12 Development Division to Materials Analysis Group

P. A. Carpenter	Voluntary resignation
A. Choudhury	Transferred to Office of Technology Transfer from Materials Analysis Group
B. L. Cox	Transferred from Y-12 Engineering Division to Ceramic Specimen Preparation Group
C. P. Haltom	Retirement
H. W. Hayden, Jr.	Transferred from K-25 AVLIS Division to Engineering Materials Section
M. G. Jenkins	Voluntary resignation
T. M. Kenney	Transferred from Y-12 Fabrication Division to Irradiated Fuels Examination Laboratory Group
H. D. Kimrey, Jr.	Transferred from Fusion Energy Division to Ceramic Processing Group
R. T. King	Transferred to Office of Technology Transfer from Space and Defense Programs
G. M. Ludtka	Transferred from Y-12 Development Division to Materials Thermal Analyses Group
G. M. Ludtka	Transferred from Y-12 Development Division to Materials Thermal Analyses Group
R. B. Ogle	Transferred from MMES Safety & Health to Environmental Safety and Health Group
R. J. Sams	Transferred from Y-12 Development Division to New Production Reactor Project Office
R. J. Sams	Transferred to Engineering Division from New Production Reactor Project Office
J. O. Scarbrough	Retirement
J. L. Scott	Transferred to Central Management Organization from Structural Materials Group
J. O. Stiegler	Transferred to Central Management Organization from Division Director
R. A. Strehlow	Retirement
F. W. Wiffen	Voluntary resignation
K. E. Wilkes	Transferred from Energy Division to Materials Thermal Analyses Group

B. Administrative and Technical Support Staff

N. M. Atchley	Retirement
J. M. Cole	Transferred from Y-12 Development Division to Research Support Group
T. L. Collins	Transferred to K-25 Health, Safety and Environmental Management from Fuel Materials Evaluation Group
C. C. Davisson	Transferred from Y-12 Quality Services Division to Ceramic Processing Group
L. M. Evans	Transferred to K-25 Engineering Division from Structural Ceramics Group
K. W. Gardner	Retirement
G. W. Garner	Transferred from Y-12 Development Division to Materials Joining Group

T. S. Geer	Transferred from Y-12 Health Physics Division to Metallography Group
D. C. Green	Transferred from Human Resources Division to High Temperature Materials Section
M. A. Hacker	Transferred from Engineering Physics and Mathematics Division to High Temperature Materials Section
C. Hamby	Retirement
D. C. Harper	Transferred from Y-12 Fabrication Division to Materials Processing Group
R. M. Holbrook	Transferred to K-25 Office of the Controller from High Temperature Materials Section
P. D. Howard	Transferred from Y-12 Metal Preparation Division to Irradiated Fuels Examination Labosatory Group
L. M. Kendrick	Voluntary resignation
J. L. Kilroy	Transferred from Human Resources Division to X-Ray Diffraction and Physical Properties Group
R. A. Lansberry	Disability
K. E. Long	Transferred to Research Reactors Division from Irradiated Fuels Examination Laboratory Group
H. F. Longmire	Transferred from Y-12 Quality Services Division to Metallography Group
L. C. Manley, Jr.	Retirement
C. J. Overton	Transferred to Chemical Technology Division from Communications and Records Support Services Group
G. W. Parks	Transferred from Plant and Equipment Division to Irradiated Materials Examination and Testing Group
R. J. Parten	Transferred from Y-12 Quality Services Division to Ceramic Manufacturability User Center Group
J. A. Patty	Transferred from Plant and Equipment Division to Irradiated Fuels Examination Laboratory Group
C. L. Rose	Transferred to Human Resources Division from Administrative and Engineering Services Group
F. A. Scarboro	Retirement
J. E. Shelton	Transferred from Y-12 Fabrication Division to Ceramic Manufacturability User Center Group
R. J. Shupe	Transferred from Fusion Energy to Materials Analysis Group
L. A. Starkey	Voluntary resignation
R. R. Steele	Transferred to K-25 Technical Services Division from Metallography Group
J. L. Varnadore	Disability

Co-Op AssignmentsCo-Op

A. M. Abeel	Virginia Polytechnic Institute and State University
N. S. Bell	Georgia Institute of Technology
D. Guerguerian	Georgia Institute of Technology
S. D. Knowles	Clemson University

N. V. McAdams	Virginia Polytechnic Institute and State University
K. M. Ploetz	Alfred University
O. J. Schwarz	Tennessee Technological University
R. E. Simpson	Georgia Institute of Technology
M. W. Stott	Tennessee Technological University
M. D. Teske	Georgia Institute of Technology
N. L. Vaughn	Tennessee Technological University
J. S. White	Tennessee Technological University

Summer Assignments (1992)

A. Summer Research Interns

T. M. Beavers	University of Tennessee
J. M. Canon	University of Missouri
J. A. Cook	University of Tennessee
E. C. Dickey	University of Kentucky
G. L. Edgemon	Georgia Institute of Technology
B. J. Reardon	Alfred University
P. A. Reichle	University of Tennessee
M. J. Swindeman	University of Tennessee
M. L. Yaklich	University of Wisconsin

B. Administrative Support Staff

J. D. Baker	Lincoln Memorial University
W. L. Fair	Carson-Newman College
D. A. Hargreaves	Tennessee Technological University
L. M. Kendrick	University of Tennessee
K. M. Marsh	University of Tennessee
S. R. Odom	Roane State Community College
H. L. Pigman	Tennessee Technological University
A. I. Price	East Tennessee State University
L. A. Reid	Samford University
J. A. Russell	Middle Tennessee State University
J. L. Walmsley	Roane State Community College

Guest Assignments

A. Scientific Staff

G. M. Adamson	Consultant
J. D. Allen	Midwest Technical
W. R. Allen	University of Tennessee
A. Arnano	Hitachi Scientific Instruments
F. W. Averill	Judson College

B. P. Bandyopadhyay	University of North Dakota
V. R. Barabash	D. F. Efremov Scientific Research Institute, Russia
D. A. Bolce	MidwestTechnical
A. Boltax	Consultant
E. S. Bomar, Jr.	Consultant
J. A. M. Boulet	University of Tennessee
L. J. Bourgeois	University of Virginia
R. H. Brown	Luther College
J. V. Cathcart	Consultant
K. K. Chawla	New Mexico Institute of Mining & Technology
B. A. Chin	Auburn University
D. L. Clark	Consultant
W. A. Coghlan	Grand Canyon College
C. Cooperrider	Hitachi Scientific Instruments
J. L. Ding	Washington State University
R. M. Diwan	Southern University
W. P. Eatherly	Consultant
S. Elliott	Hitachi Scientific Instruments
N. D. Evans, III	Oak Ridge Associated Universities
R. M. Evans	Consultant
W. H. Farmer	Consultant
J. S. Faulkner	Florida Atlantic University
J. I. Federer	Consultant
B. M. Gallois	Stevens Institute
R. J. Gray	Consultant
T. M. Gray	Gilbert Commonwealth
J. C. Griess	Consultant
D. M. Griffith	Hitachi Scientific Instruments
B. L. Gyorffy	University of Bristol, UK
R. W. Harrison	Consultant
T. Hashimoto	Hitachi Scientific Instruments
H. S. Hsu	Innovative Materials Technology Company
S. Ishiyama	Japan Atomic Energy Research Institute
S. Jitsukawa	Japan Atomic Energy Research Institute
N. R. Joshi	Prairie View A&M University
D. C. Joy	University of Tennessee
B. S. Kang	West Virginia University
Y. Katano	Japan Atomic Energy Research Institute
B. T. Kelly	Consultant
P. G. Klemens	University of Connecticut
J. I. Koike	Oregon State University
H. Kurishita	Institute for Materials Research, Tohoku University
F. W. Kutzler	Tennessee Technological University
J. C. Lee	Consultant
T. B. Lee	United Energy Services Corporation
B. C. Leslie	Consultant
W. D. Manly	Consultant
J. Marlow	Hitachi Scientific Instruments

R. E. McDonald	Consultant
D. L. McElroy	Consultant
C. J. McHargue	University of Tennessee
M. H. Melson	Digital Equipment Company
J. Miltenberger	Hitachi Scientific Instruments
S. Miura	Tokyo Institute of Technology
E. V. Nesterova	Central Scientific Research Institute, Russia
J. M. Okoh	University of Maryland Eastern Shore
P. Patriarca	Consultant
S. Peterson	Consultant
G. M. Pharr	Rice University
F. J. Pinski	University of Cincinnati
D. W. Richerson	Consultant
J. A. Rifkin	University of Connecticut
A. V. Rivas	Sigma Tech
J. O. Scarbrough	Consultant
L. B. Shaffer	Anderson College
K. Shiba	Japan Atomic Energy Research Institute
G. D. W. Smith	Oxford University, UK
L. C. Smith	United Energy Services Corporation
M. N. Srinivasan	Texas A&M University
K. Suzuki	Hitachi Scientific Instruments
Z. Szotek	SERC, Daresbury Laboratory, UK
T. Taguchi	Hitachi Scientific Instruments
W. M. Temmerman	SERC, Daresbury Laboratory, UK
C. R. Vander Linden	Vander Linden & Associates
K. Verfondern	Research Center, Jülich, Germany
F. J. Walker	University of Tennessee
B. L. Weaver	The 3M Company
R. Wells	Hitachi Scientific Instruments
D. E. Wittmer	Wittmer Consultants, Inc.
R. Yamada	Japan Atomic Energy Research Institute
Y. Ye	University of Tennessee
D. E. Zelmon	U.S. Air Force, Office of Scientific Research
P. Zschack	Oak Ridge Associated Universities

B. Post-Doctoral Program

S. C. Beecher	University of Delaware (ORAU)
G. L. Bell	Auburn University (ORAU)
K. Breder	Royal Institute of Technology, Sweden (ORAU)
A. Goyal	University of Rochester (ORAU)
S. L. Hwang	University of Michigan (ORAU)
R. Jayaram	University of Pittsburgh (ORAU)
R. Kontra	Massachusetts Institute of Technology (ORAU)
R. Kumar	University of Missouri (ORAU)
E. Lara-Curzio	Rensselaer Polytechnic Institute (ORAU)

C. K. Lin	University of Illinois (ORAU)
H. T. Lin	Auburn University (ORAU)
S. T. Mahmood	North Carolina State University (ORAU)
G. R. Rao	Auburn University (ORAU)
J. L. Robertson	Sandia National Laboratories
M. Sokolov	Moscow Institute of Atomic Energy (ORAU)
S. Srinivasan	North Carolina State University (ORAU)
S. Viswanathan	University of Pittsburgh (ORAU)
E. Voelkl	University of Tuebingen, Germany (ORAU)
X. L. Wang	Iowa State University (ORAU)
Z. L. Wang	University of Tennessee
T. R. Watkins	Penn State University (ORAU)
D. P. White	University of Connecticut (ORAU)
C. Xu	Iowa State University (ORAU)
X. Zhang	University of Kentucky

C. Graduate Students

D. Behboudi	Lehigh University
C. R. Blanchard	University of Texas
A. Bolshakov	Rice University
J. D. Crawford	North Carolina A&T State University
A. A. Fasching	Colorado School of Mines
D. W. Graham	Virginia Polytechnic Institute & State University
A. N. Gubbi	Auburn University
M. L. Jackson	Virginia Polytechnic Institute & State University
D. L. Joslin	University of Tennessee
S. Khosla	University of Tennessee
K. S. Leshkivich	University of Tennessee
J. J. Liao	Auburn University
Y. Lin	Auburn University
B. N. Lucas	University of Tennessee
N. Miriyala	University of Tennessee
K. P. Monar	University of Tennessee
M. Osborne	Rensselaer Polytechnic Institute
P. J. Othen	University of Oxford, UK
J. R. Pate	University of Illinois
D. D. Paul	Tennessee Technological University
L. M. Pike	University of Wisconsin
P. Satitpunwaycha	University of Florida
J. M. Schmitz	University of Tennessee
S. Shammugham	University of Tennessee
J. B. Sipf	University of Tennessee
L. Snead	Rensselaer Polytechnic Institute
D. M. Walukas	University of Tennessee
C. A. Wang	Auburn University
X. Wang	Iowa State University

Y. Wang — Florida Atlantic University
H. J. White — University of Tennessee

D. Undergraduate Students (Liu) Florida Atlantic University

U. K. Abdali	Cornell University
S. R. Agnew	Cornell University
K. A. Bell	College of William and Mary
M. Carballo	Florida International University
T. A. Hanft	Hofstra University
E. E. Meyer	Mount Holyoke College
S. Nijhawan	Coe College
P. J. Stephan	Woodbury College
P. C. Sundby	University of Wisconsin
M. B. Tanner	U.S. Naval Academy
D. C. Westmoreland	University of Tennessee

E. Science and Engineering Research Semester Program (SERS)

U. K. Abdali	Cornell University
L. J. Carson	Lincoln University
M. B. Chermside	Earlham College
C. E. Haberlin	Cornell University
M. S. Johnson	Hope College
K. M. Keys	Kalamazoo College
S. J. Miller	Florida Atlantic University
B. J. Reardon	Alfred University
B. R. Shelton	East Tennessee State University
S. M. Vyas	Rice University
D. A. Walko	Cornell University
S. H. Welch	College of Charleston

F. Southeastern University Research Association (SURA)

A. J. Duncan	University of Florida
R. G. Jordan	Florida Atlantic University
Y.	

G. Science Teachers Research Involvement for Vital Education Program (STRIVE)

L. T. Hixson	Cleveland High School
M. C. Rivera	Thomas Armstrong High School, Puerto Rico
T. L. Van deVate	Lenoir City High School

H. Science/Math Action for Revitalized Teaching Program/Appalachian Regional Commission (SMART/ARC)

L. E. Long	Lookout Valley Middle School

I. Teacher Research Associate Program (TRAC)

R. E. Chandler	South Oak Cliff High School
J. E. Harris	Monadnock Regional High School

J. Project SEED (Summer Educational Experience for the Disadvantaged Program)

J. L. Bunch	Clinton High School
M. Fuentes-Berrios	Emilio Delgado High School, Puerto Rico
J. E. Jimenez	University of Puerto Rico

User Facilities

A. High Temperature Materials Laboratory (HTML)

K. S. Ailey-Trent	North Carolina State University
M. Alam	New Mexico Technological University
W. K. Baxter	Coors Electronic Package Company
J. C. Birkbeck	EG&G Mound Applied Technologies
J. L. Bjerke	Caterpillar, Inc.
D. A. Bowers	McDonnell Douglas Corporation
C. R. Brooks	University of Tennessee
S. Cao	University of Tennessee
W. D. Cao	Teledyne Allvac
D. L. Carnahan	Alfred University
M. G. Carswell	Alzeta Corporation
J. Chang	Allison Gas Turbine
K. K. Chawla	New Mexico Technological University
J. A. Connally	Massachusetts Institute of Technology
J. E. Denton	Cummins Engine Company
L. J. Farthing	Stanford University
M. R. Foley	Norton Company
G. R. Fox	Penn State University
G. B. Freeman	Georgia Institute of Technology
J. M. Ghinazzi	Coors Technical Ceramics
M. J. Godbole	University of Tennessee
B. D. Harkens	Solar Turbines, Inc.
M. A. Harper	Ohio State University
L. P. Hehn	University of Florida
W. E. Hollar	The Carborundum Company
D. S. Horn	Coors Electronic Package Company
C. W. Hwang	Dow Chemical Company
L. A. Jackman	Teledyne Allvac
T. L. Jennings	Georgia Institute of Technology
J. Jo	Concurrent Technologies
D. L. Joslin	University of Tennessee
P. Khandelwhal	Allison Gas Turbine

H. E. Martin	Cornell University
C. A. McKeehan	Tosoh SMD, Inc.
M. D. Mello	Quadrax Corporation
M. N. Menon	Allied-Signal, Inc.
E. E. Meyer	Mount Holyoke College
W. T. Minehan	Coors Electronic Package Company
C. S. Moore	General Electric Aircraft Engines
R. R. Newman	Dow Chemical Company
N. J. Ninos	Alfred University
J. R. Olive	Vanderbilt University
D. L. Ouellette	Ceramic Process Systems
V. M. Parthasarathy	Solar Turbines, Inc.
D. K. Peeler	Clemson University
P. Pluvinage	University of Delaware
S. Raghuraman	University of Illinois
C. A. Randall	Penn State University
M. C. Rao	Church and Dwight Company
R. G. Rateick	Allied-Signal, Inc.
J. W. Sapp	McDonnell Douglas Corporation
M. R. Scanlon	Johns Hopkins University
C. R. Schardt	Coors Electronic Package Company
A. R. Sethuraman	University of Kentucky
R. D. Silvers	Allied-Signal, Inc.
G. V. Srinivasan	The Carborundum Co.
P. Su	University of Utah
C. Sung	GTE Laboratories Incorporated
D. J. Taylor	University of Arizona
J. A. T. Taylor	Alfred University
S. R. Taylor	Teledyne Allvac
A. J. Thom	Iowa State University
S. P. Vallandingham	Teledyne Allvac
P. J. Whalen	Allied-Signal, Inc.
K. E. Wiedemann	NASA Langley Research Center
E. D. Winters	Coors Electronic Package Company
J. S. Wolf	Clemson University
R. L. Yeckley	Norton Company
T. M. Yonushonis	Cummins Engine Company
X. Zhang	University of Tennessee
A. Zutshi	Rutgers University
3 users	(Proprietary)

B. Shared Research Equipment Program (SHaRE)

W. B. Alexander	University of Florida
I. M. Anderson	University of Minnesota
I. Baker	Dartmouth College
M. G. Burke	Westinghouse Science & Technology Center

D. L. Callahan	Rice University
C. B. Carter	University of Minnesota
R. D. Carter, Jr.	University of Michigan
A. Castagna	Rensselaer Polytechnic Institute
F. Chen	University of California at Los Angeles
Y. L. Chen	North Carolina State University
D. L. Damcott	University of Michigan
B. D. Fabes	University of Arizona
J. J. Hoyt	Washington State University
D. L. Joslin	University of Tennessee
K. H. Kim	Stevens Institute of Technology
P. G. Kotula	University of Minnesota
T. Liu	Lehigh University
D. M. Maher	North Carolina State University
M. P. Mallamaci	University of Minnesota
S. McKernan	University of Minnesota
D. C. Paine	Brown University
N. L. Petouhoff	University of California at Los Angeles
H. M. Phillips	Rice University
N. Qiu	Vanderbilt University
P. Satitpunwaycha	University of Florida
F. R. Sivazlian	North Carolina State University
N. S. Stoloff	Rensselaer Polytechnic Institute
G. Sundar	Washington State University
S. Tanaka	North Carolina State University
T. Y. Tsui	Rice University
J. E. Wittig	Vanderbilt University
Y. Zhu	Brookhaven National Laboratory

C. Oak Ridge Synchrotron Organization for Advanced Research (ORSOAR)

R. Aburano	University of Illinois
J. Anderson	University of Illinois
F. B. Arnold	University of Akron
R. Beech	University of Illinois
M. Bessier	Laboratoire pour l'Utilisation du Rayonnement Electromagnetique, France
F. Bley	Laboratoire pour l'Utilisation du Rayonnement Electromagnetique, France
T. Bohanon	Northwestern University
H. Chen	University of Illinois
J. Chen	University of Akron
S. Z. D. Cheng	University of Akron
T. C. Chiang	University of Illinois
P. Chow	University of Houston
W. Dmowski	University of Pennsylvania
M. Durbin	Northwestern University
P. Dutta	Northwestern University

T. Egami	University of Pennsylvania
B. Everitt	University of Illinois
M. Fradkin	University of Illinois
S. Fu	University of Pennsylvania
I. Fugita	University of Illinois
B. Gaulin	McMaster University, Canada
E. Hirschorn	University of Illinois
M. Homa	University of Illinois
H. Hong	University of Illinois
R. Hu	University of Pennsylvania
E. D. Isaacs	AT&T Bell Laboratories
S. Lefebvre	Laboratoire pour l'Utilisation du Rayonnement Electromagnetique, France
J. G. Lussier	McMaster University, Canada
A. Malik	Northwestern University
B. McMann	University of Illinois
J. Mikrut	Northwestern University
M. More	Nagoya University, Japan
S. Moss	University of Houston
M. Nelson	University of Illinois
K. Pettit	University of Illinois
P. Platzman	AT&T Bell Laboratories
J. L. Pong	Northwestern University
M. Radler	Dow Chemical Company
D. Rosenfield	University of Pennsylvania
M. Salamon	University of Illinois
A. Schroeder	McMaster University, Canada
T. Sendyka	University of Pennsylvania
M. C. Shih	Northwestern University
R. Simmons	University of Illinois
J. P. Simon	Laboratoire pour l'Utilisation due Rayonnement Electromagnetique, France
T. Teshi	University of Illinois
S. Teslic	University of Pennsylvania
C. Venkataraman	University of Illinois
A. Vigliante	University of Houston
Q. Wang	University of Houston
H. Williams	AT&T Bell Laboratories
P. Wochner	University of Houston
X. Yan	University of Pennsylvania
M. Yandrastits	University of Akron
S. X. Zeng	University of Illinois
A. Zhang	University of Akron

Appendix C

HONORS AND AWARDS

Compiled by Muriel Tate

The Metals and Ceramics Division at Oak Ridge National Laboratory has established a longstanding tradition of excellence. The quality of its research and the success of its development work have been the result of established ability of its scientific and engineering staff. Since the division's initial achievements, this ability has been formally recognized in the many professional honors received.

Presented below is a listing of special honors and awards accorded to divisional staff personnel during the report period. The type of recognition received varies in degree but tends to fall into one of the following generic categories: honorific and professional society awards, appointments, conference involvement, and patents issued.

HONORIFIC AND PROFESSIONAL SOCIETY AWARDS

K. B. ALEXANDER served on the 1992 Nominating Committee of the Electron Microscopy Society of America (EMSA).

M. L. ATCHLEY, R. L. BEATTY, K. S. BLAKELY, A. BLEIER, F. W. CHRISTIE, E. G. DIXON, W. H. ELLIOTT, B. G. GIESEKE, E. H. LEE, P. A. MENCHHOFER, D. H. PIERCE, W. H. WARWICK, P. J. WENZEL, AND C. G. WESTMORELAND received a Martin Marietta Energy Systems Technology Transfer Support Award, December 2, 1991.

P. F. BECHER, M. A. JANNEY, O. O. OMATETE, AND T. N. TIEGS received the Advanced Technology Award from the Inventors International Hall of Fame, November 7, 1992.

A. BLEIER, W. H. WARWICK, AND C. G. WESTMORELAND received a Martin Marietta Energy Systems Licensing Support Award for gelcasting research, December 7, 1991.

E. E. BLOOM was named a Fellow of the American Nuclear Society, November 12, 1991.

V. R. BULLINGTON AND J. O. KIGGANS received a Martin Marietta Energy Systems Licensing Support Award for silicon whisker-reinforced composites, December 7, 1992.

A. J. CARTER received a Martin Marietta Energy Systems Operations and Support Award for distinguished service to the staff of the M&C Division through enthusiastic cooperation and assistance in the area of division financial planning, internal time, and cost reporting, May 22, 1992.

B. R. CHILCOAT, C. HAMBY, AND J M ROBBINS received Outstanding Achievement Awards from the U.S. Department of Energy, October 6, 1992.

M. C. CLARK received a Martin Marietta Energy Systems Licensing Support Award for ceramic fiber-reinforced composites and ultralight EMI shielding, December 7, 1992.

K. M. COOLEY AND J. H. MILLER received a Martin Marietta Energy Systems Licensing Support Award for ceramic fiber-reinforced composites, December 7, 1992.

W. R. CORWIN received an ASTM Award of Appreciation for his leadership role in coordinating the ASTM E-10 symposium on "Small Specimen Test Techniques and Their Application to Nuclear Reactor Vessel Thermal Annealing and Plant Extension," January 29, 1992.

W. R. CORWIN received an ASTM Award of Appreciation for organizing the workshop on "Fracture Test Method Size Requirements and Related Problems," held in Pittsburgh, Pennsylvania, May 5, 1992.

D. F. CRAIG received the President's Award for Performance Improvement in recognition of significant contributions that support the values of continuous improvement and people involvement within Martin Marietta Energy Systems, Inc., August 1991.

D. F. CRAIG AND THE METALS AND CERAMICS DIVISION STAFF received a Certificate of Appreciation from the U.S. Department of Energy for outstanding commitment to increasing educational excellence in the community and to achieving the National Education Goals of America 2000, November 4, 1992.

S. A. DAVID was awarded the Comfort A. Adams Lecture Award from the AWS National Awards Committee, November 5, 1991.

S. A. DAVID was named a Corporate Fellow and received a personal commendation letter from MMES President Clyde Hopkins in recognition of his continuing accomplishments in the fields of welding, science, and technology, February 26, 1992.

S. A. DAVID received the American Welding Society Honorary Membership Award, March 25, 1992.

S. A. DAVID was named a Fellow by the American Association for the Advancement of Science (AAAS) for his significant advancement of welding science and technology through original and definitive research and for continued leadership and outstanding service to the national and international welding research community, October 5, 1992.

C. L. DOWKER received the 1992 M&C Division Administrative Support Award for Distinguished Achievement, September 17, 1992.

S. G. FRYKMAN received the 1992 M&C Division Sustained Contribution Award for Distinguished Achievement, September 17, 1992.

R. S. GRAVES received an Award for Excellence in Symposium and Publication Management from the ASTM Committee on Publications for his outstanding efforts in developing and conducting the ASTM symposium on "Insulation Materials: Testing and Applications," June 1, 1992.

M. L. GROSSBECK was named a Fellow of the American Nuclear Society for his contributions to the science and technology of nuclear energy through original and innovative research on the effects of neutron irradiation on the properties of materials and for the development of advanced structural materials for fission and fusion reactors, April 1, 1992.

F. M. HAGGAG received an ASTM Award of Appreciation for outstanding contributions to the ASTM E-10 symposium on "Small Specimen Test Techniques and Their Application to Nuclear Vessel Thermal Annealing and Plant Extension," January 29, 1992.

R. L. HEESTAND was named a Fellow by the ASM International Board of Trustees for his significant contributions to the development of advanced alloys used in energy systems, national defense, and space exploration, October 22, 1991.

HIGH TEMPERATURE MATERIALS LABORATORY was recognized for its architecture by a meritorious award from the Society of The American Institute of Architects, Tennessee, October 12, 1992.

L. L. HORTON served on the ASM International Advisory Technical Awareness Council (ATAC), the 1992 Nominating Committee, and Committee 2000.

C. R. HUBBARD received the Best Poster Paper Award for "High Speed, High Temperature XRD Data Collection Using a Position Sensitive Detector," judged the best poster in XRD applications at the 1992 Denver X-Ray Conference, Colorado Springs, Colo., July 31, 1992.

M. A. JANNEY AND O. O. OMATETE received a Silver Acorn Award for "Method for Molding Ceramic Powders Using a Water-Based Gel Casting" (Omatete's 1st patent) from the U.S. Patent Office, November 15, 1992.

M. G. JENKINS, M. K. FERBER, AND T. A. NOLAN received a Martin Marietta Energy Systems Technical Achievement Award for significant materials characterization and analysis contributions to the development and commercialization of a high-performance silicon nitride ceramic, May 22, 1992.

E. A. KENIK received the Electron Microscopy Society of America Physical Sciences Poster Award with M. G. Burke from Westinghouse Science & Technology Center, August 1992.

J. F. KING received a personal commendation letter from Dr. Alvin W. Trivelpiece in recognition of outstanding performance for his contributions to the fabrication of the propulsor for the SEAWOLF class-attack submarine within an aggressive time schedule, January 29, 1992.

J. F. KING received a Martin Marietta Energy Systems Technical Achievement Award for exceptional efforts in the propulsor fabrication for the SEAWOLF submarine, May 22, 1992.

J. F. KING was presented the President's Award for Continuous Improvement in recognition of his outstanding contributions supporting Total Quality Management objectives for the SEAWOLF Weld Improvements Project, June 17, 1992.

R. J. LAUF received an International Hall of Fame Award for Advanced Technology from the Inventors Clubs of America for his work with Don W. Bible and co-developer, Carl Everleigh, on the "Variable Frequency Microwave Furnace," September 25, 1992.

E. H. LEE, M. B. LEWIS, AND L. K. MANSUR received an R&D 100 Award for "Hard-Surfaced Polymers," June 1, 1992.

E. H. LEE received a Martin Marietta Energy Systems Licensing Support Award for nickel aluminide alloys, December 7, 1992.

M. B. LEWIS received a 1992 Technical Communication Award from the East Tennessee Chapter of the Society for Technical Communications, January 1992.

C. T. LIU AND V. K. SIKKA received the Gold and Emerald Acorn Award for "Nickel Aluminide Alloy for High Temperature Structural Use" (Liu's 15th patent) from the U.S. Patent Office, November 15, 1992.

P. J. MAZIASZ received the Significant Contribution Award from the Materials Science and Technology Division of the American Nuclear Society for his paper entitled, "Microstructural Evolution of Martensitic Steels During Fast Neutron Irradiation," November 13, 1991.

C. G. MCKAMEY was named a Corporate Honoree in the Knoxville YWCA's 1991 Tribute to Women.

J. C. MCLAUGHLIN received a Martin Marietta Energy Systems Licensing Support Award for ultralight EMI shielding, December 7, 1992.

R. K. NANSTAD was named a Fellow by the ASM International Board of Trustees for his important contributions to the fields of metal fracture and radiation effects in nuclear reactor pressure vessel steels, June 3, 1992.

R. K. NANSTAD received an ASTM Award of Appreciation for his outstanding contributions to the "16th International Symposium on the Effects of Radiation on Materials," June 1992.

D. H. PIERCE received a Martin Marietta Energy Systems Licensing Support Award for iron aluminides, December 7, 1992.

V. K. SIKKA received an International Hall of Fame Award for Advanced Technology from the Inventors Clubs of America for his work in the field of magnetohydrodynamics, November 11, 1991.

V. K. SIKKA, D. O. HOBSON, I. ALEXEFF, R. J. LAUF, AND B. HOFFHEINS were inducted into the Inventors International Hall of Fame, February 10, 1992.

V. K. SIKKA received a Martin Marietta Energy Systems Technical Achievement Award for outstanding effort in the development of nickel and iron aluminides and in the identification of commercial applications for aluminides, May 22, 1992.

V. K. SIKKA received the Silver and Ruby Acorn Award for his 5th patent, "Method for Improving Weldability of Nickel Aluminide Alloys," from the U.S. Patent Office, November 15, 1992.

G. M. SLAUGHTER was named a Member of the Fellows Committee of the American Welding Society, June 1992 through June 1995.

G. M. SLAUGHTER received the 1993 Allan Ray Putnam Service Award for sustained technical contributions in promoting the goals, objectives, and ideals of ASM International, August 24, 1992.

G. M. SLAUGHTER was named a Member of the Council of Fellows by the ASM International Board of Trustees, September 1, 1992, through August 31, 1995.

L. L. SNEAD received the American Nuclear Society Fusion Energy Division Paper Award, June 10, 1992.

G. M. STOCKS received a Martin Marietta Energy Systems Operations and Support Award for development of the Saturday Academy of Computing and Mathematics, May 22, 1992.

M. D. THREAT received the Eastern Star Award in appreciation for many years of loyal and faithful service rendered to the Order of the Eastern Star as worthy Matron and District Deputy, August 3, 1992.

T. N. TIEGS received an honorable mention for his patent, "Ductile Ni_3Al Alloys as Bonding Agents for Ceramic Materials in Cutting Tools," from the U.S. Patent Office, November 15, 1992.

T. N. TIEGS AND T. B. LINDEMER received honorable mentions for their patents, "Ceramic Composites Reinforced with Modified Silicon Carbide Whiskers" and "Modified Silicon Carbide Whiskers," from the U.S. Patent Office, November 15, 1992.

J. R. WEIR, JR., received the annual Who's Who In Tennessee Distinguished Service Award for his unselfish dedication to service to others and untiring personal effort in making the great State of Tennessee a wonderful place to live, work, and play, from Who's Who South Inc., 1991.

J. L. WRIGHT received the 1992 M&C Division Technical Support Award for Distinguished Achievement, September 17, 1992.

M. H. YOO was named a Fellow by the ASM International Board of Trustees for his outstanding research contributions in deformation twinning, void swelling, creep cavitation, small-angle neutron scattering, and strengthening and toughening mechanisms of ordered intermetallic alloys, June 3, 1992.

S. J. ZINKLE was presented the 1992 Excellence in Fusion Engineering Award by Fusion Power Associates for his outstanding initiative, creativity, leadership, and significant technical contributions made to the fundamental understanding of irradiation damage in fusion reactor candidate materials, May 27, 1992.

APPOINTMENTS

P. F. BECHER was appointed Associate Editor of the *Journal of the American Ceramic Society.*

J. BENTLEY was appointed to the Editorial Board of *Microscopy Research and Technique.*

T. M. BESMANN was appointed Associate Editor of the *Journal of the American Ceramic Society*, October 1991.

T. M. BESMANN was appointed Adjunct Professor of Materials Science and Engineering at the University of Tennessee, September 1992.

P. J. BLAU was appointed a U.S. representative to the Versailles Project on Advanced Materials and Standards (VAMAS) Working Area on Wear of Engineering Materials through October 1992.

P. J. BLAU was appointed Chairman of the ASM International Specialty Materials Division Council through October 1993.

P. J. BLAU was appointed to the International Editorial Advisory Board, *Tribology International Journal,* October 1992.

A. CHOUDHURY was appointed Vice President of the American Vacuum Society-Tennessee Valley Chapter, October 15, 1992, through October 15, 1993.

W. R. CORWIN was appointed Editor of ASTM Special Technical Publication (STP) 888 for his involvement in its preparation and as a Conference Chairman, February 14, 1992.

D. F. CRAIG was appointed Director of the ORNL M&C Division, May 18, 1992.

S. A. DAVID was appointed Adjunct Professor of Metallurgical and Materials Engineering and Research Scientist for the Center for Welding and Joining Research by the Colorado School of Mines, January 1, 1992, through December 31, 1994.

S. A. DAVID was appointed a Member of the ONR Research Opportunities in the Materials Sciences Panel, National Research Council, by the Director of the Naval Studies Board, May 27, 1992.

S. A. DAVID was appointed Chairman of the ASM Joining Division Council, October 31, 1992.

S. A. DAVID was appointed Principal Reviewer for the *Welding Journal.*

G. M. GOODWIN was appointed a Member of the Marketing Committee of the American Welding Society, June 1, 1992, through May 31, 1995.

L. L. HORTON was appointed Physical Sciences Director by the Microscopy Society of America.

L. L. HORTON was appointed a Member of the Editorial Committee of *Advanced Materials & Processes.*

C. H. HSUEH was appointed a Member of the International Editorial Board of *Composites Engineering.*

J. R. KEISER was appointed Vice Chairman of Group Committee T-2 on Energy Technology by the National Association of Corrosion Engineers, March 27, 1992.

C. T. LIU was appointed Editor of the *Journal of Intermetallics*, a new journal from Elsevier, July 1993.

C. T. LIU was appointed a Member of the International Advisory Board of the *Journal of Materials Science and Technology*, November 25, 1992.

C. T. LIU was appointed Principal Editor of the *Journal of Materials Research.*

L. K. MANSUR was appointed Editor of the *Journal of Nuclear Materials.*

L. K. MANSUR was appointed a Member of the Editorial Board of the *Journal of Materials Engineering.*

P. J. MAZIASZ was appointed Chairman of the Structures Committee of the Materials Science Division of ASM International, November 1, 1992.

M. K. MILLER was appointed Chairman of the Editorial Board of the International Field Emission Society.

M. K. MILLER was appointed to the Editorial Boards for the *Journal of Microscopy* and *Ultramicroscopy and Nanotechnology*.

D. F. PEDRAZA was appointed a Professor in Residence in the Department of Metallurgy at the University of Connecticut, March 15, 1992.

R. E. STOLLER was appointed Secretary for the American Society for Testing and Materials (ASTM) Committee E-10 on Nuclear Technology and Application, January 1992.

J. M. VITEK was appointed Chairman of the Board of Review of *Metallurgical Transactions A.*

M. H. YOO was appointed a Member of the Editorial Advisory Board of the *Journal of Intermetallics,* July 1993.

T. ZACHARIA was appointed Principal Reviewer for the *Welding Journal.*

CONFERENCES

MRS Symposium on Diamond Films, Boston, Mass., December 3-5, 1991

R. E. Clausing, Chairman

MRS Symposium on Shape-Memory and Phenomena Materials, Boston, Mass., December 3-5, 1991

C. T. Liu, Co-organizer

ASTM Committee E-10 Symposium on Small Specimen Test Techniques and Their Application to Nuclear Reactor Vessel Thermal Annealing and Plant Life Extension, New Orleans, La., January 29-31, 1992

W. R. Corwin, Co-chairman
F. M. Haggag, Co-chairman

"Science in Action/Professional Awareness Symposium," WATTec '92, Knoxville, Tenn., February 18-21, 1992

L. L. Horton, Co-chairman

TMS Symposium on Irradiation Facilities and Defect Studies, San Diego, Calif., March 3-4, 1992

L. K. Mansur, Session Chairman

Symposium on Microwave Processing of Materials III, Spring Meeting of the Materials Research Society, San Francisco, Calif., April 27 - May 2, 1992

R. L. Beatty, Organizer

Workshop on Low Expansion Ceramics, Airport Hilton, Knoxville, Tenn., April 30, 1992

D. P. Stinton, Chairman

Organizing Workshop on Fracture Test Method Size Requirements and Related Problems, Pittsburgh, Pa., May 5, 1992

W. R. Corwin, Organizer

Sixth Annual Conference on Fossil Energy Materials, Oak Ridge, Tenn., May 12-14, 1992

N. C. Cole, Chairman

CFCC Working Group Meeting, Oak Ridge, Tenn., May 14-15, 1992

M. A. Karnitz, Chairman

DOE Basic Energy Sciences/Materials Sciences Information Meeting, Oak Ridge, Tenn., May 20-22, 1992

L. L. Horton, Co-organizer and Session Chairman

37th ASME International Gas Turbine and Aeroengine Congress and Exposition, Session A, "Design, Analysis, and Life Prediction of Ceramic Components," Cologne, Germany, June 1-4, 1992

R. A. Bradley, Co-chairman
C. R. Brinkman, Session Chairman

3rd International Conference on Trends in Welding Research, sponsored by ASM International and the American Welding Society, Gatlinburg, Tenn., June 1-4, 1992

S. A. David, Co-chairman
J. M. Vitek, Co-chairman

ASTM Committee C28.01 on Properties and Performance of Advanced Ceramics, Louisville, Ky., June 18, 1992

C. R. Brinkman, Chairman

16th International Symposium on the Effects of Radiation on Materials, ASTM Committee E-10, Aurora, Colo., June 23-25, 1992

R. K. Nanstad, Co-chairman

24th National Symposium on Fracture Mechanics, ASTM Committee E-24, Gatlinburg, Tenn., June 30 - July 2, 1992

D. E. McCabe, Co-chairman

1992 NATO Advanced Study Institute, Nanophase Materials, Praia do Porto Novo, Portugal, July 4-12, 1992

W. C. Oliver, Director

Symposium on Recent Developments in Forming, Characterization, and Processing of Ceramics, 23rd Annual Meeting of the Fine Particle Society, Las Vegas, N.V., July 13-17, 1992

A. Bleier, Program Co-chairman

50th Anniversary Meeting of the Electron Microscopy Society of America, Boston, Mass., August 16-21, 1992

J. Bentley, Program Chairman
Z. L. Wang, Co-chairman

International Conference on Anomalous (Resonance) X-Ray Scattering: Theory and Experiment, Malente, Germany, August 17-21, 1992

C. J. Sparks, Jr., Co-chairman

International Intermetallics Workshop, Hangzhou, China, September 28 - October 1, 1992

C. T. Liu, Co-organizer

Advisory Technical Awareness Council (ATAC) Symposium, Fall 1992 ASM International Meeting, Chicago, Ill., October 26-28, 1992

L. L. Horton, Co-organizer and Session Chairman

International Conference on Thermal Shock and Thermal Fatigue Behavior of Advanced Ceramics, Munich, Germany, November 8-13, 1992

P. F. Becher, Co-chairman

Symposium on High-Temperature Ordered Aluminides and Intermetallics, Fall Meeting of the Materials Research Society, Boston, Mass., November 30 - December 4, 1992

C. T. Liu, Co-chairman
C. G. McKamey, Session Chairman
M. H. Yoo, Co-chairman

International Conference on Modeling and Control of Joining Processes, American Welding Society, December 1992

T. Zacharia, Chairman

PATENTS ISSUED

W. D. ARNOLD, W. D. BOND, AND R. J. LAUF, "Process for Fabricating Doped Zinc Oxide Microsphere Gel," U.S. Patent 5,062,993, November 5, 1991.

R. L. BEATTY AND R. J. LAUF, "Thermal Storage Module for Solar Dynamic Receivers," U.S. Patent 5,074,283, December 24, 1991.

D. P. STINTON, J. C. MCLAUGHLIN, AND R. A. LOWDEN, "Ceramic Fiber-Reinforced Filter," U.S. Patent 5,075,160, December 24, 1991.

V. K. SIKKA, "Ordered Iron Aluminide Alloys Having an Improved Room Temperature Ductility and Method Thereof," U.S. Patent 5,084,109, January 28, 1992.

H. D. KIMREY, M. A. JANNEY, AND M. K. FERBER, "Microwave Furnace Having Microwave Compatible Dilatometer," U.S. Patent 5,099,096, March 24, 1992.

C. T. LIU, "Castable Nickel Aluminide Alloys for Structural Applications," U.S. Patent 5,108,700, April 28, 1992.

L. K. MANSUR AND E. H. LEE, "Process for Hardening the Surface of Polymers," U.S. Patent 5,130,161, July 14, 1992.

M. A. JANNEY AND O. O. OMATETE, "Method for Molding Ceramic Powders Using a Water-Based Gel Casting Process," U.S. Patent 5,145,908, September 8, 1992.

C. E. HOLCOMBE, N. L. DYKES, AND T. N. TIEGS, "Method of Nitriding, Carburizing or Oxidizing Refractory Metal Articles Using Microwaves," U.S. Patent 5,154,779, October 13, 1992.

H. E. KIM AND A. J. MOOREHEAD, "Cesium Iodide Alloys," U.S. Patent 5,171,555, December 15, 1992.

Appendix D

SEMINAR PROGRAM

Compiled by Muriel Tate

Because effective exchange of information is so vital to scientific and technological advance, the division sponsors and maintains an active seminar program for communication of ideas and discussion of results among researchers working in the broad field of materials science and engineering. Most of the talks deal with technical topics and are presented by invited speakers affiliated with research institutions located elsewhere in North America and abroad. The actual number of talks scheduled in any given week varies but, over the year, averages more than one per week.

The seminar program is administered by a committee appointed by division management. In function, the program achieves the desired goal of providing a forum for free exchange of information and for the passage of intellectual ideas that one can criticize, react to, and act upon. In short, these periodic exchanges aid the researcher in his or her quest for new knowledge and provide stimuli for further meaningful work that enhances basic understanding. The speakers and topics of seminars presented in the past year are as follows:

B. BHUSHAN, Department of Mechanical Engineering, Ohio State University, Columbus, "Tribology of Thin Films and Bulk Ceramics and Their Applications to Magnetic Storage Devices," October 4, 1991.

R. P. MESSNER, Materials Science and Technology Division, Los Alamos National Laboratory, N.M., "Formation Kinetics of Reaction-Bonded Silicon Carbide-Based Materials," October 17, 1991.

M. ARITA, Materials Research Laboratory, Nissan Motor Co., Ltd., Yokosuka, Japan, "Investigation of the Tribological Characteristics of Solid Lubricants Exposed to Atomic Oxygen" and "Application of a Ceramic Piston Pin to an Internal Combustion Engine," October 21, 1991.

T. WATANABE, Department of Materials Science, University of Tohoku, Sendai, Japan, "Toughening of Brittle Materials by Grain Boundary Design and Control," October 25, 1991.

M. ENOKI, Research Center for Advanced Science and Technology, University of Tokyo, Komaba, Japan, "Acoustic Emission Source Characterization of Microfracture in Advanced Materials," October 29, 1991.

S. L. SASS, Department of Materials Science and Engineering, University of Cornell, Ithaca, N.Y., "The Local Compositional Order and Dislocation Structure of Grain Boundaries in Ni_3Al Alloys," October 31, 1991.

S. L. SASS, Department of Materials Science and Engineering, University of Cornell, Ithaca, N.Y., "Control of Mechanical Properties of Metal-Ceramic Interfaces," November 1, 1991.

P. G. KLEMENS, Department of Physics, University of Connecticut, Storrs, "Radiation Damage and Thermal Conductivity of Dielectric Solids," November 6, 1991.

A. AKAY, Department of Mechanical Engineering, Wayne State University, Detroit, "Interaction of Friction and Vibration," November 7, 1991.

H. CAI, McCormick School of Engineering and Applied Science, Northwestern University, Evanston, Ill., "Crack Bridging by Inclined Fibers/Whiskers in Ceramic Composites," December 2, 1991.

E. LARA-CURZIO, Center of Composite Materials and Structures, Rensselaer Polytechnic Institute, Troy, N.Y., "Thermo-Mechanical Characterization of SiC Fibers at Elevated Temperatures," December 13, 1991.

J. MANCUSO, Advanced Microscopy Techniques, Boston, "Development of an Electro-Optical Interface for TEMS," January 8, 1992.

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Appendix E

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Appendix F

PRESENTATIONS AT TECHNICAL MEETINGS

Compiled by Sherry Hempfling

Seventh Annual National American Welding Research Conference, Columbus, Ohio, October 2–4, 1991:

T. ZACHARIA* AND S. A. DAVID, "Computer Modeling of Arc Welds to Predict Effects of Critical Variables on Weld Penetration"

United States Advanced Ceramics Association (USACA) Structural Ceramics Meeting, Washington, D.C., October 2, 1991:

V. J. TENNERY, "DOE HTML Fellowship Program—Transportation Technologies"

Carolina's Northern Piedmont Chapter, ASM International, Winston-Salem, North Carolina, October 3, 1991:

L. L. HORTON, "Materials R&D to Enable Tomorrow's Technologies: An Overview of Activities in the Metals and Ceramics Division of Oak Ridge National Laboratory"

Technology Transfer Meeting, Scottsbluff, Nebraska, October 4, 1991:

J. R. WEIR, JR., "The Development and Commercialization of New Materials"

Reactor Vessel Thermal Annealing Planning Group Meeting, Washington, D.C., October 4, 1991:

S. K. ISKANDER,* W. R. CORWIN, AND R. K. NANSTAD, "Plans for Materials Studies on Annealing and Reembrittlement Within the Heavy-Section Steel Irradiation Program"

International Symposium on Terminology and Documentation in Specialized Communication, Ontario, Canada, October 7–8, 1991:

R. A. STREHLOW,* T. O. TALLANT, J. D. MASON, AND P. L. KIENLEN, "Text Encoding for Retrieval of Scientific and Technical Information (STI)"

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*Speaker

Seminar at the University of Tennessee, Knoxville, October 8, 1991:

M. K. MILLER, "The Miscibility Gap in the Fe-Cr System"

Presentation to Staff Members of Lawrence Berkeley Laboratory, Berkeley, California, October 10, 1991:

E. H. LEE, "Ion Implantation as a Tool for the Study of Materials"

Second ASTM Symposium on Insulation Materials: Testing and Applications, Gatlinburg, Tennessee, October 10–12, 1991:

J. E. CHRISTIAN,* G. E. COURVILLE, R. S. GRAVES, R. L. LINKOUS, D. L. MCELROY, F. J. WEAVER, AND D. W. YARBROUGH, "In Situ and Thin-Specimen Aging of Experimental Polyisocyanurate Roof Insulation Foamed with Alternative Blowing Agents"

R. S. GRAVES, D. W. YARBROUGH, D. L. MCELROY,* AND H. A. FINE, "Steady-State and Transient Results on Insulation Materials"

T. G. KOLLIE,* H. A. FINE, R. S. GRAVES, K. W. CHILDS, AND F. J. WEAVER, "Vacuum Insulation: The Technological Challenges to the Successful Application of this Super Insulation"

D. W. YARBROUGH,* R. S. GRAVES, AND J. E. CHRISTIAN, "HCFC-22 as an Alternative Blowing Agent for Closed-Cell Foamboard Insulation"

180th Meeting of The Electrochemical Society, Phoenix, Arizona, October 13–17, 1991:

P. F. TORTORELLI* AND J. R. KEISER, "The Measurement of the Mechanical Properties of Oxide Scales by Submicron Indentation Testing"

ALCOA Laboratories Technical Symposium on Computational Metallurgy, Nemacolin Woodlands, Pennsylvania, October 13–18, 1991:

L. K. MANSUR, "Defect Reactions, Clustering, and Property Changes in Irradiated Materials"

ASTM Symposium on Multiaxial Fatigue, San Diego, California, October 14–15, 1991:

K. C. LIU, "A Method for Multiaxial Fatigue Life Prediction Using Energy-Based Approaches"

International Energy Agency (IEA) Annex II Executive Committee Meeting, Nagoya, Japan, October 15, 1991:

V. J. TENNERY, "Status of U.S. Research in Subtask 5, IEA Annex II"

Electric Power Research Institute (EPRI) Ninth Particulate Control Symposium, Williamsburg, Virginia, October 16, 1991:

L. R. WHITE, "Ceramic Filters for Use at High Temperatures"

American Ceramic Society (Acers) Fall Meeting on Atomic Structure, Bonding, and Properties of Ceramics, Macro Island, Florida, October 16–19, 1991:

R. MCKEE, "Layer-by-Layer Growth of Oxide Ceramics"

U.S.–Russia Working Group 3 Meeting of the Joint Coordinating Committee for Civilian Nuclear Reactor Safety (JCCCNRS), Oak Ridge, Tennessee, October 18, 1991:

M. K. MILLER, "Atom Probe Field Ion Microscopy Studies of Irradiation Hardening on an Ultrafine Scale"

R. K. NANSTAD, "ORNL Test Results of U.S.S.R. Unirradiated Compact and Charpy Impact Specimens"

R. K. NANSTAD, "Review of Data Related to Inhomogeneity of Plates, Forgings, and Welds for U.S. Reactor Vessels"

Joint Electronics Glass and Optical Materials Division Meeting, Crystal City, Virginia, October 20–23, 1991:

T. M. BESMANN, "Chemical Vapor Deposition"

1991 TMS/ASM Fall Meeting, Cincinnati, Ohio, October 20–24, 1991:

D. J. ALEXANDER* AND G. M. GOODWIN, "Thick-Section Weldments in 21-6-9 and 316LN Stainless Steel for Fusion Applications"

D. J. ALEXANDER* AND V. K. SIKKA, "Mechanical Properties of Advanced Nickel Aluminides"

D. J. ALEXANDER,* J. M. VITEK, AND S. A. DAVID, "The Effect of Long-Term Aging on the Mechanical Properties of Type 308 Stainless Steel Welds"

F. C. CHEN, A. J. ARDELL,* AND D. F. PEDRAZA, "Amorphization of Zr_3Al Under 3.8 MeV Zr^{3+} Ion Bombardment"

R. E. CLAUSING,* L. HEATHERLY, L. L. HORTON, E. D. SPECHT, AND Z. L. WANG, "Structural Development of Diamond Films"

S. A. DAVID, "Weld Pool Solidification and Microstructures"

B. G. GIESEKE* AND V. K. SIKKA, "Mechanical Properties of Ductile Fe_3Al-Based Alloy Plate"

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J. A. HORTON,* C. T. LIU, AND C. G. MCKAMEY, "Interfacial Structure and Properties of Ni_3Al Alloys and Composites"

D. M. KROEGER,* A. GOYAL, H. HSU, F. A. LIST, AND V. K. SIKKA, "Melt-Processed Y123 and BSCCO Deposits and Tapes"

J. J. LIAO,* E. P. GEORGE, E. K. OHRINER, AND R. H. ZEE, "Grain Boundary Chemistry of Iridium Alloys Doped with Th, Y, and Lu"

C. T. LIU, "Environmental Embrittlement in Intermetallic Compounds"

M. C. MAGUIRE,* M. L. SANTELLA, AND B. K. DAMKROGER, "Factors Controlling Sub-Solidus Cracking During Fusion Welding"

E. K. OHRINER* AND E. P. GEORGE, "Intermetallic Layer Growth in the Iridium-Molybdenum System"

J. E. PAWEL,* C. J. MCHARGUE, L. J. ROMANA, AND J. J. WERT, "Adhesion Enhancement of Iron Films to Sapphire by Implantation of Cr, Ni, or Fe"

D. F. PEDRAZA* AND J. A. CARO, "The Role of Point Defects in the Amorphization of Intermetallic Compounds"

M. L. SANTELLA, "Fundamental Metallurgical Considerations in Brazing and Soldering"

G. M. STOCKS,* D. M. NICHOLSON, W. A. SHELTON, F. J. PINSKI, D. D. JOHNSON, J. B. STAUNTON, B. L. GYÖRFFY, A. BARBIERI, B. GINATEMPO, P. E. A. TURCHI, AND M. SLUITER, "Ordering Mechanisms in Metallic Alloys"

M. H. YOO* AND C. L. FU, "Cleavage Strength of B2-Type and $L1_2$-Type Intermetallic Alloys"

T. ZACHARIA,* S. A. DAVID, AND J. M. VITEK, "Effect of Convection on Weld Pool Development"

1st International Symposium on the Science of Engineering Ceramics, Koda, Japan, October 21–23, 1991:

P. F. BECHER,* K. B. ALEXANDER, AND H. T. LIN, "Development of Toughened Ceramics for Elevated Temperatures"

D. A. KOESTER, R. F. DAVIS,* AND K. L. MORE, "Steady-State Creep of Hot-Pressed SiC Whisker-Reinforced Silicon Nitride"

K. L. MORE, D. A. KOESTER, AND R. F. DAVIS, "Microstructural Analysis and Mechanisms of Deformation of Hot-Pressed SiC Whisker-Reinforced Silicon Nitride"

U.S.–Russia Working Group 3 Meeting of the Joint Coordinating Committee for Civilian Nuclear Reactor Safety (JCCCNRS), Rockville, Maryland, October 22, 1991:

R. K. NANSTAD,* D. E. MCCABE, F. M. HAGGAG, AND S. K. ISKANDER, "Comparison of Charpy Impact Toughness, Fracture Toughness, and Crack-Arrest Toughness for Two Irradiated High-Copper Welds"

Third AIST-NEDO/DOE-HQ Joint Technical Meeting on Materials for Coal Liquefaction, Fukuoka City, Japan, October 23, 1991:

R. R. JUDKINS, "Development of Iron Aluminides for Coal Conversion and Utilization"

J. R. KEISER, A. J. PATKO, AND R. R. JUDKINS,* "Materials Performance at the Wilsonville Coal Liquefaction Facility: 1989–1991"

U.S. DOE Conference on Electron Microscopy, Livermore, California, October 23–25, 1991:

W. E. MODDEMAN,* D. P. KRAMER, W. C. BOWLING, L. F. ALLARD, AND D. W. COFFEY, "Detection of Zerovalent Nickel in Glass as Characterized by Transmission Electron Microscopy (TEM) and X-Ray Photoelectron Spectroscopy (XPS)"

International Symposium on Advanced Ceramics IV at Kanagawa Science Park, Kanagawa, Japan, October 24–25, 1991:

P. F. BECHER,* K. B. ALEXANDER, AND A. BLEIER, "The Effect of Microstructure on Transformation Toughening in Zirconia Ceramics and Composites"

19th Water Reactor Safety Information Meeting, Rockville, Maryland, October 28-30, 1991:

W. R. CORWIN, "Heavy-Section Steel Irradiation Program: Embrittlement Issues"

1991 Annual Automotive Technology Development Contractors' Coordination Meeting (ATD/CCM), Dearborn, Michigan, October 28–31, 1991:

P. J. BLAU, "Relating Laboratory Friction Coefficient Values to Practical Applications"

P. J. BLAU, "The Cost-Effective Ceramic Machining Program Plan"

M. K. FERBER* AND M. G. JENKINS, "Evaluation of the Elevated-Temperature Mechanical Reliability of a HIPed Silicon Nitride"

C. S. YUST, "The Wear Mode Transition Surface for a Ceramic Composite"

C. S. YUST, "Wear Mode Transition in a Silicon Nitride-Silicon Carbide Whisker Composite"

Second International Conference on Uranium Hexafluoride Handling, Oak Ridge, Tennessee, October 29, 1991:

J. H. DEVAN, "Investigation of Breached Depleted UF_6 Cylinders"

Steam Generator Advisory Group, Sand Key, Florida, October 30, 1991:

C. V. DODD* AND J. D. ALLEN, JR., "Neural Network Analysis of Eddy-Current Data From Inspection of Generator Tubing"

The 10th International Congress on Applications of Laser and Electro-Optics (ICALEO '91), San Jose, California, November 3–8, 1991:

S. A. DAVID* AND J. M. VITEK, "Rapid Solidification Effects During Laser Welding"

Art Career Fair Day, Maryville College, Maryville, Tennessee, November 5, 1991:

J. W. NAVE, "Research and Development Photography"

International Conference on Evolution in Beam Applications, Takasaki, Japan, November 5–8, 1991:

L. K. MANSUR,* E. H. LEE, M. B. LEWIS, AND S. J. ZINKLE, "Applications of Multiple-Ion Irradiations to Metals, Ceramics and Polymers"

American Nuclear Society (ANS) 1991 Winter Meeting, San Francisco, California, November 10–14, 1991:

R. H. COOPER AND J. P. MOORE,* "Materials in Space Nuclear Power Systems"

Invited Seminar at University of Utah, Salt Lake City, Utah, November 12, 1991:

M. A. JANNEY, "Microwave Processing of Ceramic Materials"

National Educators' Workshop: Update 91, Standard Experiments in Engineering Materials Science and Technology, Oak Ridge, Tennessee, November 12–14, 1991:

D. F. CRAIG, "Structural Ceramics"

L. L. HORTON, "Science in Action: An Interdisciplinary Science Education Program"

L. L. HORTON, "The Microscopic World: A Demonstration of Electron Microscopy for Younger Students"

J. O. STIEGLER, "Accessing National Laboratories for Research and Development Opportunities"

R. A. STREHLOW, "Standard Terminology in the Laboratory and Classroom"

Meeting at Oak Ridge Associated Universities, Oak Ridge, Tennessee, November 13, 1991:

S. MILLER, "Toughening of Rare-Earth-Based, Magnetic Alloy"

B. SHELTON, "Thermomechanical Processing Optimization for Fe_3Al-Based Alloys for Maximizing Room-Temperature Ductility"

S. VYAS, "Effect of Aluminum Content, Alloying Additions, Annealing Temperature, and Quenching Medium on Mechanical Properties of Wrought Iron Aluminide"

Wekstoffe and Bauweisen neuer Technologie in der Luft-und Raumfahrt, Hamburg, Germany, November 13–15, 1991:

P. GRAHLE,* J. RÖSLER, J. SCHNEIBEL, AND E. ARZT, "High-Strength Low-Density Materials on the Basis of ODS Intermetallic Phases"

U.S./Japan Second Specialized Topic Workshop on Pressurized Thermal Shock, San Diego, California, November 14, 1991:

R. K. NANSTAD,* D. J. ALEXANDER, AND F. M. HAGGAG, "Effects of Low-Temperature Thermal Annealing on Type 308 Stainless Steel Weld Metals"

Science Fair, Maryville College, Maryville, Tennessee, November 16, 1991:

J. W. NAVE, "Research and Development Photography"

Fifth International Conference on Fusion Reactor Materials (ICFRM-5), Clearwater, Florida, November 17–22, 1991:

D. J. ALEXANDER,* G. M. GOODWIN, AND E. E. BLOOM, "Thick-Section Weldments in 21-6-9 and 316LN Stainless Steel for Fusion Energy Applications"

W. R. ALLEN* AND S. J. ZINKLE, "Implantations of Helium in Sapphire and Magnesium Oxide: Behavior on an Atomic-Scale"

G. E. C. BELL, "Lithium Purification at Temperatures Below 500° C"

G. E. C. BELL* AND T. INAZUMI, "Radiation-Induced Sensitization to Corrosion In Fusion Reactor Materials"

G. E. C. BELL,* E. A. KENIK, AND L. HEATHERLY, JR., "Characterization of Radiation-Induced Segregation in Austenitic Stainless Steels Using Analytical Electron Microscopy and Scanning Auger Microprobe Techniques"

G. E. C. BELL,* E. A. KENIK, AND T. INAZUMI, "Electrochemical and Microstructural Properties of Austenitic Stainless Steel Irradiated by Heavy Ions Above 600° C"

T. D. BURCHELL,* W. P. EATHERLY, J M ROBBINS, AND J. P. STRIZAK, "The Effects of Neutron Irradiation on the Structure and Properties of Carbon-Carbon Composite Materials"

F. W. CLINARD, JR.,* E. H. FARNUM, D. L. GRISCOM, R. F. MATTAS, S. S. MEDLEY, F. W. WIFFEN, S. S. WOJTOWICZ, K. M. YOUNG, AND S. J. ZINKLE, "Materials Issues in Diagnostic System for BPX and ITER"

M. L. GROSSBECK,* P. J. MAZIASZ, AND A. F. ROWCLIFFE, "Modeling of Strengthening Mechanisms in Irradiated Fusion Reactor First Wall Alloys"

D. R. HARRIES,* G. J. BUTTERWORTH, A. HISHINUMA, AND F. W. WIFFEN, "Evaluation of Reduced-Activation Options for Fusion Materials Development"

T. INAZUMI, G. E. C. BELL,* P. J. MAZIASZ, AND T. KONDO, "Radiation-Induced Sensitization of Ti-Modified Austenitic Stainless Steel Irradiated in Spectrally Tailored Experiment at 60–400° C"

S. JITSUKAWA,* M. L. GROSSBECK, AND A. HISHINUMA, "Stress-Strain Relations of Irradiated Stainless Steels Below 473 K"

S. JITSUKAWA,* K. HOJOU, M. SUZUKI, A. HISHINUMA, AND E. A. KENIK, "Segregation at Radiation-Induced Defects and at Grain Boundaries of Austenitic Stainless Steels"

S. JITSUKAWA,* P. J. MAZIASZ, T. ISHIYAMA, L. T. GIBSON, AND A. HISHINUMA, "Tensile Properties of Austenitic Stainless Base-Metal and Weld-Joint Specimens Irradiated in ORR Spectrally Tailored Experiments"

Y. KATOH,* Y. KOHNO, A. KOHYAMA, AND R. E. STOLLER, "Effects of Damage Rate and/or He/DPA Ratio on Microstructural Evolution in Irradiated Austenitic Steel"

E. A. KENIK* AND K. HOJOU, "Radiation-Induced Segregation in FFTF-Irradiated Austenitic Stainless Steels"

R. L. KLUEH AND D. J. ALEXANDER,* "Heat Treatment Effects on Toughness of Irradiated 9Cr–1MoVNb and 12Cr–1MoVW Steels"

R. L. KLUEH* AND K. EHRLICH, "Ferritic/Martensitic Steels for Fusion Reactor Applications"

R. L. KLUEH* AND P. J. MAZIASZ, "Effect of Irradiation in HFIR on Tensile Properties of Cr-Mo Steels"

A. KOYAMA,* M. L. GROSSBECK, AND G. PIATTI, "The Application of Austenitic Stainless Steels in Advanced Fusion Systems: Current Limitations and Future Prospects"

T. KONDO,* D. G. DORAN, K. EHRLICH, AND F. W. WIFFEN, "The Status and Prospects of High-Energy Neutron Test Facilities for Fusion Materials Development"

L. K. MANSUR* AND M. L. GROSSBECK, "Irradiation Creep by Transient Point Defect Processes"

P. J. MAZIASZ, "Temperature Dependence of the Dislocation Microstructure of PCA Austenitic Stainless Steel Irradiated in ORR Spectrally Tailored Experiments"

P. J. MAZIASZ, "Void Swelling Resistance of Phosphorus-Modified Austenitic Stainless Steels During HFIR Irradiation to 57 dpa at 300 to 500°C"

G. R. RAO,* E. H. LEE, L. A. BOATNER, B. A. CHIN AND L. K. MANSUR, "Multiple Ion Implantation Effects on Hardness and Fatigue Properties of Fe–13Cr–15Ni Alloys"

G. R. RAO,* E. H. LEE, B. A. CHIN, AND L. K. MANSUR, "Multiple Ion Implantation Effects on Fatigue Properties of Fe-Ni-Cr Alloys"

T. SAWAI, P. J. MAZIASZ, H. KANAZAWA, AND A. HISHINUMA,* "Microstructural Evolution of Austenitic Stainless Steels Irradiated in Spectrally Tailored Experiments in ORR at 400°C"

L. L. SNEAD,* D. STEINER, AND S. J. ZINKLE, "Measurement of the Effect of Radiation Damage to Ceramic Composite Interfacial Strength"

L. L. SNEAD,* D. STEINER, AND S. J. ZINKLE, "Radiation-Induced Microstructure and Mechanical Property Evolution of SiC/C/SiC Composite Materials"

R. E. STOLLER,* R. H. GOULDING, AND S. J. ZINKLE, "Measurement of Dielectric Properties in Alumina Under Ionizing and Displacive Irradiation Conditions"

M. SUZUKI,* A. HISHINUMA, N. YAMANOUCHI, T. TAMURA, AND A. F. ROWCLIFFE, "Alloy Preparation for Studying the Effect of Hydrogen Production During Neutron Irradiation Using an ^{54}Fe Isotope"

M. SUZUKI,* P. J. MAZIASZ, S. JITSUKAWA, S. HAMADA, AND A. HISHINUMA, "Chemical Compositional Change in Precipitates During HFIR Irradiation in Austenitic and Ferritic Steels"

P. F. TORTORELLI, "Dissolution Kinetics of Steels Exposed in Lead-Lithium and Lithium Environments"

P. F. TORTORELLI,* G. E. C. BELL, AND E. A. KENIK, "Effects of Compositional Modifications on the Sensitization Behavior of Fe-Cr-Mn Austenitic Steels"

C. A. WANG,* H. T. LIN, M. L. GROSSBECK, AND B. A. CHIN, "Suppression of HAZ Cracking During Welding of Helium-Containing Materials"

R. YAMADA,* S. J. ZINKLE, AND G. P. PELLS, "Radiation Damage in Al_2O_3 and $MgAl_2O_4$ Preimplanted with H, He, C and Irradiated with Ar^+ Ions"

S. J. ZINKLE, "Anisotropic Dislocation Loop Nucleation in Ion-Irradiated $MgAl_2O_4$"

S. J. ZINKLE, "Anomalous Microstructural Effects Associated with Light Ion Irradiation of Ceramics"

S. J. ZINKLE* AND E. R. HODGSON, "Radiation-Induced Changes in the Physical Properties of Ceramic Materials"

U.S./Japan Workshop Q-142 on High Heat Flux Components and Plasma Surface Interactions for Next Devices, Santa Fe, New Mexico, November 25–28, 1991:

T. D. BURCHELL, "Irradiation Induced Dimensional and Property Changes in 2D and 3D Carbon-Carbon Composite Materials"

Workshop on Radiation Damage Correlation Methodology, Hitchin, United Kingdom, December 2–4, 1991:

R. E. STOLLER, "Damage Exposure Units and Data Correlation: Summary of Recent International Workshops"

R. E. STOLLER, "Modeling the Effects of Irradiation Temperature and Damage Rate on Radiation-Induced Embrittlement"

Materials Research Society 1991 Fall Meeting, Boston, Massachusetts, December 2–6, 1991:

K. B. ALEXANDER, A. GOYAL,* D. M. KROEGER, V. SELVAMANICAM, AND K. SALAMA, "Microstructure and Current Transport Within Domains of Melt-Processed $YBa_2Cu_3O_{7-\delta}$"

L. F. ALLARD,* F. J. WALKER, AND R. A. MCKEE, "MBE Growth of Epitaxical Perovskites on Silicon: The Atomic Structure of BATIO3/BAO Interfaces by High Resolution Electron Microscopy"

J. BENTLEY,* L. J. ROMANA, L. L. HORTON, AND C. J. MCHARGUE, "Distribution and Characterization of Iron in Implanted Silicon Carbide"

A. BLEIER, "Characterization and Control of Particle Surface Chemistry in the Aqueous Processing of Al_2O_3-ZrO_2 Composites"

A. BLEIER, "Effects of Surface Charge on the Processing of Silicon Slurries in Nonaqueous Media"

W. H. BUTLER, "Multiple Scattering Theory with Space Filling Potentials"

W. H. BUTLER* AND X.-G. ZHANG, "The Nature of the Wave Function in Multiple Scattering Theory"

W. H. BUTLER,* X.-G. ZHANG, AND A. GONIS, "An Exact Cellular Method and Its Relation to Multiple Scattering Theory"

E. P. GEORGE,* C. T. LIU, J. A. HORTON, C. J. SPARKS, M. Y. KAO, H. KUNSMANN, AND T. KING, "Microstructure, Phase Stability, Mechanical Properties, and Shape Memory Characteristics of Ni-Fe-Al-B Alloys"

A. GOYAL,* S. J. BURNS, W. C. OLIVER, P. D. FUNKENBUSCH, AND D. M. KROEGER, "Mechanical Properties of Highly Aligned Melt-Textured $YBa_2Cu_3O_{7-\delta}$"

A. GOYAL,* F. A. LIST, AND D. M. KROEGER, "Highly Aligned Melt-Textured Thick Films of $YBa_2Cu_3O_{7-\delta}$ on Compatible Flexible Substrates"

J. A. HORTON,* E. P. GEORGE, M. Y. KAO, T. KING, C. J. SPARKS, L. L. TANNER, AND P. THOMA, "Characterization of the Phase Transformation in the Shape Memory Alloy Ni-36 at. % Al"

D. D. JOHNSON, J. B. STAUNTON, F. J. PINSKI, B. L. GYÖRFFY, AND G. M. STOCKS, "Compositional Disorder, Magnetism, and Their Interplay in Metallic Alloys"

D. L. JOSLIN,* L. J. ROMANA, C. J. MCHARGUE, AND P. A. THÉVENARD, "Temperature Effects in Ion Beam Mixing of Oxide-Oxide Interfaces"

D. L. JOSLIN,* L. J. ROMANA, C. W. WHITE, AND C. J. MCHARGUE, "Ion Beam Modification of Metal-Sapphire Interfaces by Oxygen Implantation"

E. A. KENIK, "Comparison of Thermally and Irradiation-Induced Grain Boundary Segregation in Austenitic Stainless Steels"

F. A. LIST,* H. HSU, O. B. CAVIN, W. D. PORTER, T. J. HENSON, B. J. REARDON, C. R. HUBBARD, AND D. M. KROEGER, "Phase Development in the $Bi_2Sr_2CaCu_2O_y$ System: Effects of Oxygen Pressure"

D. M. NICHOLSON,* R. H. BROWN, W. H. BUTLER, H. YANG, J. W. SWIHART, P. B. ALLEN, A. MEHTA, AND L. M. SCHWARTZ, "First-Principles Calculation of Residual Resistivity"

D. M. NICHOLSON, W. H. BUTLER, R. H. BROWN, H. YANG, J. W. SWIHART, AND P. B. ALLEN, "First-Principles Resistivity in Disordered Alloys"

J. E. PAWEL, C. J. MCHARGUE, L. J. ROMANA, D. J. DOWNING, AND J. J. WERT, "Using Weibull Statistics to Analyze Ion-Beam-Enhanced Adhesion as Measured by the Pull Test"

J. E. PAWEL,* C. J. MCHARGUE, L. J. ROMANA, AND J. J. WERT, "The Role of Ion Species on the Adhesion Enhancement of Ion Beam Mixed Fe/Al_2O_3 Systems"

A. J. PEDRAZA, M. J. GODBOLE, AND L. ROMANA,* "Substrate Surface Effects on the Properties of Sputter-Deposited and Laser-Irradiated Films"

D. F. PEDRAZA, "The Behavior of Interstitials in Irradiated Graphite"

X. QIU, A. K. DATYE,* R. T. PAINE, AND L. F. ALLARD, "The Oxidation Stability of Boron Nitride Thin Films on Ceramic Substrates"

G. R. RAO,* E. H. LEE, AND L. K. MANSUR, "Structure and Dose Effects on Ion Beam Surface Modification of Polymers"

L. ROMANA,* J. PAWEL, A. J. PEDRAZA, AND M. J. GODBOLE, "Substrate Surface Effects on the Properties of Deposited Films"

L. ROMANA,* D. F. PEDRAZA, AND W. R. ALLEN, "High Energy Zirconium Implantation in Sapphire"

B. W. SHELDON,* P. A. REICHLE, AND T. M. BESMANN, "In Situ Light-Scattering Measurements During the CVD of Polycrystalline Silicon Carbide"

G. M. STOCKS,* D. M. NICHOLSON, W. A. SHELTON, G. A. GEIST, F. J. PINSKI, A. BARBIERI, B. L. GYÖRFFY, B. GINATEMPO, Z. SZOTEK, AND W. M. TEMMERMAN, "KKR-CPA Theory of the Electronic Structure and Energetics of Partially Ordered Intermetallic Alloys"

X. WANG,* X.-G. ZHANG, W. H. BUTLER, B. N. HARMON, AND G. M. STOCKS, "Relativistic Multiple Scattering Theory for Space Filling Potentials"

T. L. WARD,* T. T. KODAS, S. W. LYONS, D. KROEGER, J. BRYNESTAD, AND H. HSU, "Characteristics and Processing Behavior of Pb-Bi-Sr-Ca-Cu-O Powders Produced Using Aerosol Decomposition"

R. L. WEAVER AND W. H. BUTLER,* "Scattering and Multiple Scattering in Disordered Materials, An Overview"

X.-G. ZHANG, "Real-Space Multiple Scattering Theory Method: Formalism and Applications"

Seminar at Mount Holyoke College, Holyoke, Massachusetts, December 4, 1991:

L. F. ALLARD, "Electron Holography: Techniques and Perspectives for Materials Science"

Seminar at Eastman Kodak, Rochester, New York, December 6, 1991:

W. C. OLIVER,* B. N. LUCAS, AND G. M. PHARR, "The Mechanical Characterization of Thin Film Using Indentation Experiments"

ORAU Presentation, Weinberg Auditorium, Oak Ridge National Laboratory, Oak Ridge, Tennessee, December 6, 1991:

S. MILLER, "Toughening of Rare-Earth-Based, Magnetic Alloy"

B. SHELTON, "Optimization of Thermomechanical Processing of Fe_3Al-Based Alloys for Maximizing Room-Temperature Ductility"

S. VYAS, "Effect of Aluminum Content, Annealing Temperature, and Quenching Medium on Mechanical Properties of Iron Aluminide Alloys"

U.S.–Argentina Workshop on Fracture and Welding, Buenos Aires, Argentina, December 10–12, 1991:

S. A. DAVID, "Advances in Welding Science and Technology"

2nd Japan International SAMPE Symposium and Exhibition, Chiba, Japan, December 11–14, 1991:

E. P. GEORGE* AND C. T. LIU, "Grain Boundary Fracture and Alloy Design of Intermetallics"

Presentations at the Argentine Atomic Energy Commission Facilities at Buenos Aires, Argentina, and Bariloche, Argentina, December 13–17, 1991:

S. A. DAVID, "Advances in Welding Science and Technology"

Seminar at Tohoku University, Sendai, Japan, December 18, 1991:

E. P. GEORGE, "Deformation and Fracture of $L1_2$ Trialuminides"

Seminar at the National Research Institute for Metals (NRIM), Tokyo, Japan, December 19–20, 1991:

E. P. GEORGE, "Grain Boundary Fracture and Alloy Design of Intermetallics"

American Association of Physics Teachers, Winter Meeting, Orlando, Florida, January 4, 1992:

T. DOLNEY* AND A. CHOUDHURY, "Data Processing of 3-D SIMS Ion Images on a Macintosh IICX"

16th Annual Conference on Composites and Advanced Ceramics, ASTM Committee C-28, Cocoa Beach, Florida, January 5–10, 1992:

T. M. BESMANN,* T. S. MOSS, J. C. MCLAUGHLIN, AND B. W. SHELDON, "Kinetics and Model Validation for Chemical Vapor Infiltration of SiC/Nicalon"

M. K. FERBER,* R. L. JACKSON, M. G. JENKINS, R. A. LOWDEN, AND K. K. CHAWLA, "Evaluation of the Interfacial Mechanical Properties in Fiber-Reinforced Ceramic Composites"

W. E. MODDEMAN,* D. P. KRAMER, W. C. BOWLING, L. F. ALLARD, AND D. W. COFFEY, "Examinations by TEM, EDS, and XPS of Lithia-Alumina-Silica (LAS) Glass/Nickel and Iron Interfaces"

B. W. SHELDON,* T. F. MORSE, J. RANKIN, R. A. LOWDEN, L. RIESTER, AND T. M. BESMANN, "The Stability of Optical Fibers During the Formation of Ceramic Matrix Composites by Chemical Vapor Infiltration"

V. J. TENNERY, "Status of Tensile Strength Analysis, GN-10 Silicon Nitride, 25° C"

T. N. TIEGS,* P. F. BECHER, H. T. LIN, P. A. MENCHHOFER, AND J. O. KIGGANS, JR., "Microstructure Development During High-Temperature Annealing of Sintered Si_3N_4"

9th Symposium on Space Nuclear Power Systems, Albuquerque, New Mexico, January 12–16, 1992:

A. CHOUDHURY,* J. R. DISTEFANO, AND J. W. HENDRICKS, "Secondary Ion Mass Spectrometry (SIMS) Analysis of Nb-1% Zr Alloys"

E. K. OHRINER,* G. M. GOODWIN, AND D. A. FREDERICK, "Weldability of DOP-26 Iridium Alloy: Effects of Welding Gas and Alloy Composition"

Graduate Seminar, University of New Mexico, Albuquerque, New Mexico, January 17, 1992:

A. CHOUDHURY, "Surface Analysis Techniques and Applications: An Introduction"

Seminar at the Max-Planck-Institut für Wekstoffwissenschaft, Stuttgart, Germany, January 20, 1992:

P. F. BECHER, "Microstructural Design of Toughened Ceramics"

Seminar at the Institut für Festkörperforschung (Solid State Physics), Forschungszentrum, Jülich, Germany, January 21, 1992:

S. J. ZINKLE, "Radiation Damage Studies in Ceramics Using Transmission Electron Microscopy"

Joint Monbusho/Japan Atomic Energy Research Institute (JAERI)/U.S. DOE Workshop on Mid-Program Review of Progress, Honolulu, Hawaii, January 24–25, 1992:

J. E. PAWEL,* M. L. GROSSBECK, D. J. ALEXANDER, G. E. LUCAS, AND A. W. LONGEST, "HFIR Fracture Toughness Experiments"

ASTM Symposium on Small Specimen Test Techniques and Their Applications to Nuclear Reactor Vessel Thermal Annealing and Plant Life Extension, New Orleans, Louisiana, January 29–31, 1992:

D. J. ALEXANDER, "Fracture Toughness Measurements with Subsize Disk Compact Specimens"

C. A. WANG,* M. L. GROSSBECK, AND B. A. CHIN, "TEM Disc Welder to Investigate the Susceptibility of Candidate Nuclear Materials to Helium-Induced Weld Cracking"

American Vacuum Society 21st Annual Symposium, Florida Chapter, Largo, Florida, February 3–5, 1992:

W. B. ALEXANDER,* P. H. HOLLOWAY, L. HEATHERLY, AND R. E. CLAUSING, "Crystallite Geometry of HFCVD Diamond"

Diamond Films for Transportation Application Workshop, Co-sponsored by the DOE Office of Transportation Technologies and Argonne National Laboratory, Argonne, Illinois, February 4–5, 1992:

R. E. CLAUSING, "Properties of Diamond and Diamond-like Films"

Fourth International Symposium on Advanced Nuclear Research—Roles and Direction of Materials Science in Nuclear Technology, Mito, Japan, February 5–7, 1992:

E. E. BLOOM, "Advanced Materials—The Key to Attractive Magnetic Fusion Power Reactors"

Presentation at Garrett Corporation, Torrance, California, February 7, 1992:

T. A. NOLAN,* L. F. ALLARD, K. L. MORE, AND V. J. TENNERY, "The High Temperature Materials Laboratory at Oak Ridge National Laboratory (ORNL)"

Australian Conference on Electron Microscopy (ACEM-12) and Workshop on EDS and EELS in Materials Science, University of Western Australia, Perth, Australia, February 9–14, 1992:

J. BENTLEY, "Energy-Dispersive X-Ray Spectrometry in an Analytical Electron Microscope"

J. BENTLEY, "Sublattice Occupancies in Intermetallic Alloys by ALCHEMI"

Z. L. WANG AND J. BENTLEY,* "REM and REELS of Oxide Ceramics"

U.S. DOE Advanced Heat Exchangers Program Review Meeting, Herndon, Virginia, February 13, 1992:

J. R. KEISER,* J. I. FEDERER, AND W. H. ELLIOTT, "Materials Support for Advanced Heat Exchangers Program"

Departmental Seminar at Georgia Institute of Technology, Atlanta, Georgia, February 14, 1992:

R. E. STOLLER, "The Influence of Radiation on the Dielectric Properties of Ceramic Materials Intended for Use in Fusion Reactors"

Seminar at the Australian Nuclear Science and Technology Organization (ANSTO), Lucas Heights Research Laboratories, Sydney, Australia, February 17, 1992:

J. BENTLEY,* K. B. ALEXANDER, N. D. EVANS, P. S. SKLAD, AND Z. L. WANG, "Analytical Electron Microscopy of Ceramics"

Drummond Workshop on Analytical Electron Microscopy, University of Sydney, Sydney, Australia, February 18–19, 1992:

J. BENTLEY,* E. A. KENIK, N. D. EVANS, K. B. ALEXANDER, P. S. SKLAD, AND Z. L. WANG, "Microanalysis of Materials by Analytical Electron Microscopy"

J. BENTLEY* AND Z. L. WANG, "Surface Analysis by Reflection Electron Energy Loss Spectrometry"

J. BENTLEY,* Z. L. WANG, S. J. PENNYCOOK, AND D. E. JESSON, "Z-Contrast Imaging in STEM, TEM, and SREM"

WATTec 1992 Conference, Knoxville, Tennessee, February 18–21, 1992:

P. J. BLAU, "Cost-Effective Ceramic Machining Program of the Department of Energy"

C. V. DODD* AND J. D. ALLEN, JR., "Neural Network Analysis of Eddy-Current Data from Inspection of Steam Generator Tubing"

1992 U.S. DOE High-Temperature Superconductors (HTS) Wire Development Workshop, Richmond, Virginia, February 19–20, 1992:

D. M. KROEGER,* J. BRYNESTAD, A. GOYAL, H. HSU, R. KONTRA, F. A. LIST, V. K. SIKKA, E. D. SPECHT, Z. L. WANG, AND R. K. WILLIAMS, "Processing of High-Temperature Superconducting Materials"

Graduate Student Seminar, University of Dayton, Dayton, Ohio, February 21, 1992:

C. R. BRINKMAN, "Development of Life Prediction Methodologies for Ceramics Used in Gas Turbine Engines"

Seminar at Commonwealth Scientific and Industrial Research Organization (CSIRO), Division of Materials Science and Technology, Melbourne, Australia, February 21, 1992:

J. BENTLEY,* E. A. KENIK, N. D. EVANS, K. B. ALEXANDER, P. S. SKLAD, AND Z. L. WANG, "Electron Microscopy Research in Materials Science at ORNL"

Seminar at Hahn-Meitner Institute, Berlin, Germany, February 24, 1992:

S. J. ZINKLE, "Microstructural Changes in Irradiated Copper"

Texas Center for Superconductivity University of Houston Science Center (TCSUHSC), High-Temperature Superconductivity (HTS) Workshop on Materials, Bulk Processing, and Applications, Houston, Texas, February 27-28, 1992:

D. M. KROEGER,* A. GOYAL, Z. L. WANG, F. A. LIST, AND K. B. ALEXANDER, "Substrate Reactions and Flux Pinning Structures in Melt-Processed $YBa_2Cu_3O_7$ Deposits on Ag-Pd Alloy Substrates"

Meeting with General Motors Corporation at Oak Ridge National Laboratory, Oak Ridge, Tennessee, February 27, 1992:

G. M. LUDTKA, "Quench Simulator"

Discussions at Advanced Materials and Technology Research Laboratories, Nippon Steel Corporation, Kawasaki, Japan, February 28, 1992:

J. M. VITEK, "Non-Equilibrium Solidification in Stainless Steels"

ORAU Guest Lecture Program at the University of North Carolina, Department of Materials Science and Engineering, Charlotte, North Carolina, February 28, 1992:

L. F. ALLARD, "Electron Holography: Techniques and Perspectives for Materials Science"

1992 TMS Annual Meeting, San Diego, California, March 1-5, 1992:

D. S. EASTON, "Melt Spinning of Lithium Hydride"

P. M. HAZZLEDINE AND J. H. SCHNEIBEL,* "Theory of Cobble Creep in Two Dimensions"

L. K. MANSUR, "Perspectives and Opportunities for Research in Radiation Effects on Materials in the 1990s"

C. G. MCKAMEY,* P. F. TORTORELLI, J. H. DEVAN, E. P. GEORGE, M. HOWELL, AND T. HIRANO, "A Study of Intermediate Temperature (400-600°C) Pest Oxidation in $MoSi_2$"

E. K. OHRINER,* C. G. MCKAMEY, AND E. P. GEORGE, "External Oxidation of Thorium in an Iridium Alloy as a Cause of Accelerated Grain Growth"

R. E. PAWEL,* D. K. FELDE, G. L. YODER, M. T. MCFEE, AND B. H. MONTGOMERY, "Cladding Corrosion Studies Under Heat Transfer Conditions for the Advanced Neutron Source"

L. REINHARD,* J. L. ROBERTSON, S. C. MOSS, G. E. ICE, P. ZSCHACK, AND C. J. SPARKS, "Anomalous X-Ray Scattering Study of Local Order in bcc $Fe_{0.53}Cr_{0.47}$"

A. F. ROWCLIFFE* AND E. E. BLOOM, "Development of Materials for Fusion Reactors"

J. H. SCHNEIBEL,* E. P. GEORGE, AND C. G. MCKAMEY, "Fabrication and Strength of Ni_3Al Reinforced with Continuous, Single Crystal Al_2O_3 Fibers"

G. M. STOCKS,* D. M. NICHOLSON, W. A. SHELTON, F. J. PINSKI, B. GINATEMPO, AND B. L. GYÖRFFY, "Ordering Energies and Ordering Mechanisms in B2 Phase NiAl"

S. VISWANATHAN* AND H. D. BRODY, "The Relation of Solidification Parameters to Microporosity in Al-4.5% Cu Alloy Castings"

Tennessee Valley Chapter of the American Vacuum Society Meeting, Oak Ridge, Tennessee, March 5, 1992:

C. R. HUBBARD, "The High Temperature Materials Laboratory—A National User Facility"

8th International Conference on Thermal Insulation, San Francisco, California, March 9–11, 1992:

R. S. GRAVES, "Thermal Resistivities for Low-Density Loose-Fill Cellulosic Insulation"

Presentation at General Motors Corporation Research Laboratories, Warren, Michigan, March 10, 1992:

G. M. LUDTKA, "Quench Simulator"

Seminar at the University of Tennessee, Department of Materials Science and Engineering, Knoxville, Tennessee, March 12, 1992:

M. H. YOO, "Effects of Elastic Anisotropy on Mechanical Behavior of Intermetallic Compounds"

Engineering Foundation Conference on Dispersion and Aggregation: Fundamentals and Applications, Palm Coast, Florida, March 15–20, 1992:

M. A. JANNEY, "A Round-Robin for Particle Electrophoresis Standardization"

O. O. OMATETE* AND A. BLEIER, "Evaluation of Dispersants for Gelcasting"

American Physical Society Meeting, Indianapolis, Indiana, March 16–20, 1992:

A. GONIS,* P. P. SINGH, P. E. A. TURCHI, M. SLUITER, D. D. JOHNSON, F. J. PINSKI, AND G. M. STOCKS, "KKR-CPA Study of Al-Li Alloys in the Atomic Sphere Approximation (ASA)"

G. E. ICE,* C. J. SPARKS, A. HABENSCHUSS, AND L. B. SHAFFER, "Anomalous X-Ray Scattering Measurement of Pair Correlations in NiFe Alloys"

E. D. ISAACS, P. M. PLATZMAN, H. WILLIAMS, P. ZSCHACK, AND G. E. ICE,* "Dynamic Structure Factor of an Electron Liquid in Aluminum"

R. KUMAR, C. J. SPARKS,* T. SHIRAISHI, AND K. HISATSUNE, "Order in Ni/Pd Substitutional CuAuI Alloys"

C. J. SPARKS* AND R. KUMAR, "Site Occupations and Phase Changes from Cr Additions in an $Al_{62.5}Cr_{7.5}Ti_{30}$ Alloy"

G. M. STOCKS, W. A. SHELTON, D. M. NICHOLSON,* G. A. GEIST, F. J. PINSKI, A. BARBIERI, AND B. L. GYÖRFFY, "Fermi Surface Nesting and Pre-Martensitic Phonon Softening in β-Phase NiAl"

J. C. SWIHART,* W. H. BUTLER, G. B. ARNOLD, AND F. M. MUELLER, "Boson Linewidth in High-Temperature Superconductors"

X. WANG,* W. H. BUTLER, X.-G. ZHANG, AND A. GONIS, "Full Cell Multiple Scattering Theory and Its Relativistic Extension"

Y. WANG,* J. S. FAULKNER, G. M. STOCKS, AND D. M. NICHOLSON, "Calculations on the Single-Site Potential for the Korringa-Kohn-Rostoker Coherent Potential Approximation from an Extended Green's Function"

X.-G. ZHANG* AND W. H. BUTLER, "The Green Function Cellular Method"

Instructional Presentation to Reactor Operators, HFIR Site, Oak Ridge National Laboratory, Oak Ridge, Tennessee, March 18 and 25, 1992, and April 1, 8, and 15, 1992:

K. FARRELL, "Behavior of Metals in Nuclear Reactors"

Meeting with ALCOA Aluminum Company at Oak Ridge National Laboratory, Oak Ridge, Tennessee, March 18, 1992:

G. M. LUDTKA, "Quench Simulator"

G. M. LUDTKA, "Superplasticity and Superplastic Forming"

73rd Annual American Welding Society (AWS) Convention, Chicago, Illinois, March 22–27, 1992:

J. M. VITEK, S. A. DAVID,* AND D. J. ALEXANDER, "475°C Embrittlement of Type 308 Stainless Steel Weld Metal"

Seminar at the University Claude Bernard-Lyon I, Physics Department, Villeurbanne, France, March 23, 1992:

D. L. JOSLIN, "Ion Beam Mixing of Oxide-Oxide Interfaces"

S. J. ZINKLE, "Effect of Irradiation on the Microstructure and Electrical Properties of Ceramics"

U.S./Japan Workshop on Structural Materials, Berkeley, California, March 24–25, 1992:

D. J. ALEXANDER* AND G. M. GOODWIN, "Thick-Section Weldments in Type 316LN Stainless Steel for Fusion Energy Applications"

Nuclear Regulatory Commission (NRC) Aging Research Information Conference, Upton, New York, March 24–27, 1992:

W. R. CORWIN, "Managing Irradiation Embrittlement in Aging Reactor Pressure Vessels"

Discussions at the Institut für Materialforschung I, Kernforschungszentrum Karlsruhe (KfK) Nuclear Research Center, Karlsruhe, Germany, March 26–27, 1992:

S. J. ZINKLE, "Effect of Irradiation on the Microstructure and Electrical Properties of Ceramics"

Sixth National Conference on Undergraduate Research, University of Minnesota, Minneapolis, Minnesota, March 26-28, 1992:

D. A. WALKO* AND E. D. SPECHT, "Characterizing Ion-Implanted Crystals with X-Ray Reflectivity"

Presentation at General Motors Corporation Research Laboratories, Warren, Michigan, March 27, 1992:

G. M. LUDTKA, "Superplasticity and Superplastic Forming (Experimental Facilities and Computer Modeling)"

G. M. LUDTKA* AND R. L. BRIDGES, "Metal Matrix Composites, Rheocasting—Compocasting—Thixocasting—Thixoforging (Semi-solid Metal Processing)"

R. E. PRICE AND G. M. LUDTKA,* "Thermal Coating Facility (Plasma Spray Capabilities)"

1992 American Society for Nondestructive Testing (ASNT) Spring Conference, Orlando, Florida, March 30–April 3, 1992:

R. W. MCCLUNG* AND D. R. JOHNSON, "Nondestructive Testing of Ceramics for Vehicular Advanced Heat Engines"

Neutron Interactive Materials Program Review Meeting, Knoxville, Tennessee, March 30–April 1, 1992:

D. J. ALEXANDER,* M. L. GROSSBECK, J. E. PAWEL, AND A. F. ROWCLIFFE, "Fracture Toughness Measurements on Irradiated Stainless Steels"

Seminar at Carborundum Company, Niagara Falls, New York, April 2, 1992:

L. F. ALLARD* AND D. W. COFFEY, "Structure and Morphology of Carborundum VLS Silicon Carbide Whiskers"

Interagency Advanced Power Group, Reston, Virginia, April 2, 1992:

R. H. COOPER, "Materials for Space Nuclear Propulsion Systems"

1992 International Conference on Metallurgical Coatings and Thin Films, San Diego, California, April 6–10, 1992:

W. B. ALEXANDER, P. H. HOLLOWAY,* L. HEATHERLY, AND R. C. CLAUSING, "Crystallite Geometry of HFCVD Diamond"

W. C. OLIVER,* B. N. LUCAS, AND G. M. PHARR, "The Mechanical Characterization of Thin Films Using Indentation Experiments"

International Atomic Energy Agency (IAEA) Interregional Training Course on Safety Aspects of Aging and Related Maintenance in Nuclear Power Plant Operation, Argonne, Illinois, April 10, 1992:

W. R. CORWIN, "Management of Aging of the Primary Pressure Boundary: Focus on the Reactor Pressure Vessel"

94th Annual Meeting of the American Ceramic Society (ACerS), Minneapolis, Minnesota, April 12–16, 1992:

K. B. ALEXANDER* AND P. F. BECHER, "The Microstructure of Interfaces in Silicon Carbide Whisker-Reinforced Alumina Composites"

K. B. ALEXANDER,* P. F. BECHER, AND A. BLEIER, "Analysis of Grain Size Distributions in Alumina-Zirconia Composites"

L. F. ALLARD,* T. A. NOLAN, M. G. JENKINS, AND V. J. TENNERY, "The Microstructure vs Mechanical Properties of a Commercial Silicon Nitride"

P. F. BECHER,* K. B. ALEXANDER, AND A. BLEIER, "Effect of Grain Size and Composition on Both the Transformation Temperature and Toughening in the Al_2O_3-ZrO_2 (12 mol % CeO_2) System"

A. BLEIER, "Models of the Oxide-Solution Interface"

A. CHOUDHURY,* D. L. JOSLIN, C. W. WHITE, C. J. MCHARGUE, AND L. J. ROMANA, "XPS Characterization of Ion Implanted Oxide Films on Sapphire"

R. B. DINWIDDIE* AND T. D. BURCHELL, "The Effect of Neutron Irradiation on the Thermal Conductivity of Graphite and Carbon-Carbon Composites"

R. B. DINWIDDIE* AND J M ROBBINS, "Thermal Conductivity of Carbon-Bonded Carbon Fiber Insulation for Radioisotope Space Power Systems"

G. R. FOX,* S. B. KRUPANIDHI, K. L. MORE, AND L. F. ALLARD, "Microstructure/ Property Relations of Lead Lanthanum Titanate Thin Films"

C. H. HSUEH, "Requirements of Frictional Debonding for Tough Fiber-Reinforced Ceramic Composites"

C. R. HUBBARD,* O. B. CAVIN, AND J. GHINAZZI, "HTXRD Study of the Phase Evolution During Firing of Green Alumina"

C. R. HUBBARD,* S. A. DAVID, AND S. SPOONER, "Nondestructive Residual Stress Mapping in High Temperature Materials"

C.-K. J. LIN* AND D. F. SOCIE, "Static and Cyclic Fatigue of Alumina at Room and High Temperatures"

H. T. LIN,* P. F. BECHER, W. H. WARWICK, AND T. N. TIEGS, "Strength and Toughness Behavior of In Situ Reinforced Si_3N_4 Ceramics"

K. L. MORE,* V. J. TENNERY, AND N. L. HECHT, "Microstructural Evolution During the Tensile Static and Cyclic Fatigue of Silicon Nitride"

S. NATANSOHN,* A. E. PASTO, AND W. J. ROURKE, "Effect of Surface Modifications on the Properties of Silicon Nitride Ceramics"

T. A. NOLAN,* L. F. ALLARD, D. W. COFFEY, M. K. FERBER, AND K. L. MORE, "Microstructure and Failure Mechanisms in Creep and Fatigue Tested Silicon Nitride Ceramics"

O. O. OMATETE,* A. BLEIER, AND C. G. WESTMORELAND, "Rheological Properties of Gelcasting Ceramic Slurries"

B. J. REARDON* AND C. R. HUBBARD, "Using Simulated XRD Patterns in New Materials Analysis"

T. N. TIEGS,* J. O. KIGGANS, JR., AND K. L. PLOETZ, "Cost-Effective Sintered Reaction-Bonded Silicon Nitride (SRBSN) for Structural Ceramics"

T. N. TIEGS,* S. D. NUNN, AND P. A. MENCHHOFER, "Gas-Pressure Sintering of Si_3N_4 with Mixed Rare Earth Additives"

A. A. WERESZCZAK* AND A. PARVIZI-MAJIDI, "Crack-Wake Toughening Mechanisms at High Temperatures in an Extruded Alumina Short-Fiber/Cordierite Matrix Composite"

S. G. WINSLOW* AND D. R. JOHNSON, "Development of a Cost Effective Silicon Nitride Powder in DOE's Ceramic Technology Project"

9th International Conference on Wear of Materials, San Francisco, California, April 13–17, 1992:

G. R. RAO,* E. H. LEE, AND L. K. MANSUR, "Structure and Dose Effects on Improved Wear Properties of Ion-Implanted Polymers"

Predictive Heat Treatment Meeting at the General Motors Gear Center, Romulus, Michigan, April 14–15, 1992:

G. M. LUDTKA, "Quench Simulator"

Seminar at State University of New York at Buffalo, Buffalo, New York, April 15–16, 1992:

J. H. SCHNEIBEL, "Processing and Properties of Intermetallic-Matrix Composites"

3M Technical Forum, Symposium on Advanced Inorganic Materials, St. Paul, Minnesota, April 17, 1992:

O. O. OMATETE, "Ceramic Forming by Gelcasting"

Workshop/Meeting—Combustion 2000 Project, Andover, Massachusetts, April 21–22, 1992:

V. J. TENNERY AND K. BREDER,* "Material Support for the HITAF. Generating Mechanical Properties Data for Two SiC Materials"

Frontiers of Electron Microscopy in Materials Science Conference, Oakland, California, April 21–24, 1992:

L. F. ALLARD,* T. A. NOLAN, D. C. JOY, T. HASHIMOTO, X.-G. ZHANG, AND Y. ZHANG, "Digital Imaging for High Resolution Electron Holography"

J. BENTLEY, "Is Quantitative ALCHEMI of Intermetallic Alloys Viable?"

D. C. JOY,* X.-G. ZHANG, Y. ZHANG, T. HASHIMOTO, L. F. ALLARD, AND T. A. NOLAN, "Practical Aspects of Electron Holography"

K. L. MORE,* B. W. SHELDON, T. M. BESMANN, AND T. S. MOSS, "Nucleation and Growth of Polycrystalline SiC During Chemical Vapor Deposition"

Z. L. WANG* AND J. BENTLEY, "REM Imaging of Surface Microstructure and Dynamic Processes on Ceramic Bulk Crystals at High Temperatures"

X.-G. ZHANG,* D. C. JOY, T. HASHIMOTO, Y. ZHANG, L. F. ALLARD, AND T. A. NOLAN, "Electron Holography of Ferroelectric Domain Walls"

Y. ZHANG,* R. D. BUNN, D. C. JOY, X. ZHANG, L. F. ALLARD, T. A. NOLAN, AND T. HASHIMOTO, "Software for Electron Holography"

Discussions at Hikari Works, Nippon Steel Corporation, Hikari, Japan, April 24, 1992:

J. M. VITEK, "Phase Stability in Austenitic Stainless Steels"

Materials Research Society 1992 Spring Meeting, San Francisco, California, April 27–May 1, 1992:

D. W. BIBLE,* R. J. LAUF, AND C. A. EVERLEIGH, "Multikilowatt Variable Frequency Microwave Furnace"

A. BLEIER, O. O. OMATETE,* AND C. G. WESTMORELAND, "Rheology of Zirconia-Alumina Gelcasting Slurries"

M. A. JANNEY, H. D. KIMREY, AND J. O. KIGGANS, JR., "Microwave Processing of Ceramics: Guidelines Used at the Oak Ridge National Laboratory"

J. O. KIGGANS, JR.,* AND T. N. TIEGS, "Characterization of Sintered Reaction-Bonded Silicon Nitride Processed by Microwave Heating"

J. O. KIGGANS, JR.,* AND T. N. TIEGS, "Properties of Sintered Silicon Nitride and Sintered Reaction-Bonded Silicon Nitride Processed by Conventional and Microwave Heating"

H. D. KIMREY, "Modeling and Experiment Design Using a Quasi-Optical Approach"

R. J. LAUF,* C. HAMBY, C. E. HOLCOMBE, AND W. F. VIEROW, "Microwave Processing of Tantalum Capacitor Anodes"

R. J. LAUF,* C. E. HOLCOMBE, AND C. HAMBY, "Microwave Sintering of Multilayer Ceramic Capacitors"

O. O. OMATETE,* A. BLEIER, AND C. G. WESTMORELAND, "Rheology of Zirconia-Alumina Gelcasting Slurries"

A. R. SETHURAMAN,* J. M. STENCEL, O. B. CAVIN, AND C. R. HUBBARD, "In-Situ High Temperature X-Ray Diffraction Studies of Nanocrystalline Iron Carbides

Z. L. WANG,* A. GOYAL, D. M. KROEGER, AND T. ARMSTRONG, "Defects Near the $Y_2BaCuO_5/YBa_2Cu_3O_{7-x}$ Interface and Their Effect on Flux-Pinning in Melt-Processed and Quench-Melt-Growth-Processed $YBa_2Cu_3O_{7-x}$"

The National Association of Corrosion Engineers (NACE) Annual Conference and Corrosion Show, Nashville, Tennessee, April 27, 1992:

N. C. COLE* AND R. R. JUDKINS, "Overview of the DOE-Fossil Energy AR&TD Materials Program Regarding Corrosion Issues"

J. H. DEVAN* AND P. F. TORTORELLI, "High Temperature Corrosion of Iron Aluminides"

Discussions at the National Research Institute for Metals (NRIM), Tokyo, Japan, April 27, 1992:

J. M. VITEK, "Non-Equilibrium Solidification in Stainless Steels"

Seminar at Coors Electronic Packaging Company, Chattanooga, Tennessee, April 28, 1992:

A. BLEIER, "Colloid Science is Basic to Ceramic Processing"

C. R. HUBBARD,* S. SPOONER, S. A. DAVID, T. A. DODSON, AND M. G. JENKINS, "Nondestructive Residual Stress Mapping in High Temperature Materials"

Symposium on Materials Engineering via Micromechanics, ASME Summer Mechanics, Materials, and Aerospace Engineering Meeting, Arizona State University, Tempe, Arizona, April 28–May 1, 1992:

P. F. BECHER, "The Toughening Contribution of Crack Bridging Mechanisms in Ceramics Reinforced with Discontinuous Phases"

11th International Conference on Nondestructive Evaluation (NDE), Albuquerque, New Mexico, April 29–May 3, 1992:

C. V. DODD* AND J. D. ALLEN, JR., "Automated Analysis of Eddy-Current Steam-Generator Data"

Ceramic Material Testing Coordination Meeting, Allison Gas Turbines, Indianapolis, Indiana, May 5, 1992:

V. J. TENNERY, "IEA Annex II, Subtask 5—Status of Tensile Strength Analysis GN-10 Silicon Nitride, 25° C"

M. K. FERBER, "Creep and Fatigue Behavior of Silicon Nitride"

ASTM Committee E-24 on Fracture Test Methods Size Requirements and Related Problems, Pittsburgh, Pennsylvania, May 5, 1992:

D. E. MCCABE* AND B. D. MACDONALD, "Effects of Side Grooving in Fracture Testing"

D. E. MCCABE* AND J. G. MERKLE, "Effects of Specimen Size in K_{Ic} Fracture of Pressure Vessel Steels"

Meeting at Auburn University, Auburn, Alabama, May 6, 1992:

E. H. LEE, "Ion Implantation as a Tool for the Study of Polymeric Materials"

1992 Spring Workshop, University of Minnesota, Center for Interfacial Engineering, Minneapolis, Minnesota, May 12–14, 1992:

W. C. OLIVER* AND D. B. MARSHALL, "Measurement of Interfacial Mechanical Properties in Fiber-Reinforced Ceramic Composites"

Sixth Annual Conference on Fossil Energy Materials, Oak Ridge, Tennessee, May 12-14, 1992:

D. J. ALEXANDER* AND V. K. SIKKA, "Fracture Behavior of Iron Aluminides"

D. J. ALEXANDER* AND V. K. SIKKA, "Fracture of Iron-Aluminide Alloys"

J. H. DEVAN* AND P. F. TORTORELLI, "Environmental Effects on Iron Aluminides"

C. T. LIU, "Development of Cr_2Nb Alloys for High-Temperature Applications"

C. G. MCKAMEY,* T. ZACHARIA, AND P. J. MAZIASZ, "Development of Weldable High-Strength Iron Aluminide

P. F. TORTORELLI,* J. H. DEVAN, AND L. J. CARSON, "High-Temperature Oxidation of Cr-Nb Alloys"

Fifth International Conference on Creep of Materials, Orlando, Florida, May 17–21, 1992:

M. K. FERBER* AND M. G. JENKINS, "Empirical Evaluation of Tensile Creep and Creep Rupture in a HIPed Silicon Nitride"

R. W. SWINDEMAN AND P. J. MAZIASZ,* "The Mechanical and Microstructural Stability of Austenitic Stainless Steels Strengthened by MC-Forming Elements"

Conference on Synthesis and Processing of High-Temperature Materials for the Year 2000, St. Louis, Missouri, May 17-22, 1992:

T. M. BESMANN,* D. P. STINTON, AND R. A. LOWDEN, "Chemical Vapor Infiltration"

Fusion Energy Advisory Committee Meeting, University of California, Los Angeles, California, May 19-21, 1992:

E. E. BLOOM, "Development of Structural Materials for Fusion"

Advisory Committee on Reactor Safeguards (ACRS) Review of General Electric PRISM, San Francisco, California, May 21, 1992:

C. R. BRINKMAN, "Materials Issues Associated With Advanced Liquid-Metal Reactor Development"

National Institute of Standards and Technology (NIST) Conference on Accuracy in Powder Diffraction II, Gaithersburg, Maryland, May 25-29, 1992:

O. B. CAVIN,* C. R. HUBBARD, AND P. J. MAZIASZ, "High Temperature X-Ray Diffraction Determination of Phase Transitions in Large Grain Alloys"

C. R. HUBBARD,* T. A. DODSON, S. A. DAVID, AND S. SPOONER, "Nondestructive Residual Stress Mapping by Neutron and X-Ray Diffraction Methods"

American Carbon Society Workshop on Interfacial Phenomena at Carbon Surfaces, Atlanta, Georgia, May 25-27, 1992:

E. L. FULLER, JR., "Kinetics and Mechanisms of Corrosion of Nuclear Grade Graphites: Graphite-Gas Interactions"

Third International Symposium on High-Temperature Corrosion and Protection of Materials, Les Embiez, France, May 25-29, 1992:

J. H. DEVAN, P. F. TORTORELLI,* U. K. ABDALI, AND C. G. MCKAMEY, "The Nature of Oxide Scales Grown on Iron Aluminides at High Temperature"

P. F. TORTORELLI, "Mechanical Properties of Chromia Scales"

Workshop on Superabrasives and Grinding Wheel Technology for Machining Ceramics, Oak Ridge, Tennessee, May 28, 1992:

B. L. COX, "Overview of the Ceramic Specimen Preparation User Center, High Temperature Materials Laboratory"

Department Seminar, Chemical Engineering and Materials Science, University of Minnesota, Minneapolis, Minnesota, June 1-2, 1992:

J. BENTLEY, "Fine Structure in Electron Energy Loss Spectrometry"

J. BENTLEY, "Materials Science Applications of Electron Energy Loss Spectrometry in the Analytical Electron Microscope"

Third International Conference on Trends in Welding Research, Gatlinburg, Tennessee, June 1-5, 1992:

D. J. ALEXANDER* AND G. M. GOODWIN, "Mechanical Properties of Thick-Section Weldments in Type 316LN Stainless Steel"

D. J. ALEXANDER,* J. M. VITEK, AND S. A. DAVID, "Long-Term Aging of Type 308 Stainless Steel Welds: Effects on Properties and Microstructure"

S. A. DAVID* AND J. M. VITEK, "Principles of Weld Solidification and Microstructures"

C. R. HUBBARD* AND S. SPOONER, "Nondestructive Three-Dimensional Mapping of Residual Stress by Neutron and X-Ray Diffraction Methods"

J. H. ROOT,* T. M. HOLDEN, J. SCHRODER, S. SPOONER, C. R. HUBBARD, T. A. DODSON, AND S. A. DAVID, "Residual Stress Measurement in a Multipass Ferritic Steel Weldment by Neutron Diffraction"

S. SPOONER,* S. A. DAVID, J. H. ROOT, T. M. HOLDEN, M. A. M. BOURKE, AND J. GOLDSTONE, "Residual Stress and Strain Measurements in an Austenitic Steel Plate Containing a Multipass Weld"

J. M. VITEK,* M. RAPPAZ, S. A. DAVID, AND L. A. BOATNER, "Grain Competition in Bicrystal Welds"

C. A. WANG,* M. L. GROSSBECK, AND B. A. CHIN, "Stress Modified Welding Process for Post-Irradiated Materials"

T. ZACHARIA,* S. A. DAVID, AND J. M. VITEK, "Understanding Heat and Fluid Flow in Linear GTA Welds"

1992 Society for Experimental Mechanics (SEM) Seventh International Congress on Experimental Mechanics, Las Vegas, Nevada, June 8-11, 1992:

M. G. JENKINS, "Effect of Bending on the Room-Temperature Tensile Strengths of Structural Ceramics"

M. G. JENKINS,* M. K. FERBER, AND J. A. SALEM, "Creep and Slow Crack Growth Mechanisms Related to Macroscopic Creep Behaviour of a Silicon Nitride Ceramic at Elevated Temperatures"

66th Colloid and Surface Science Symposium, Morgantown, West Virginia, June 14–17, 1992:

E. L. FULLER, JR.,* O. C. KOPP, AND A. D. UNDERWOOD, "Evaluation of Surface Structure and Chemistry of Graphites"

O. C. KOPP,* A. D. UNDERWOOD, R. R. STEELE, AND E. L. FULLER, JR., "The Effects of Trace Elements on the Surface Oxidation of H-451 Graphite"

A. D. UNDERWOOD,* E. L. FULLER, JR., AND O. C. KOPP, "Reaction of Air With Nuclear Grade Graphite"

American Society for Testing and Materials (ASTM) G-2 Workshop on Selection and Use of Specimen Cleaning for Wear Testing, Louisville, Kentucky, June 17, 1992:

P. J. BLAU* AND R. L. JACKSON, "Specimen Cleaning Effect on the Friction Break-in Behavior in Sliding Wear Tests"

Fusion Energy Division Advisory Committee Information Meeting, Y-12 Facility, Oak Ridge, Tennessee, June 17–18, 1992:

E. E. BLOOM, "Overview of ORNL Fusion Materials Program"

Seminar at Hughes Research Laboratories, Malibu, California, June 19, 1992:

E. H. LEE, "Ion Implantation as a Tool for the Study of Polymeric Materials"

16th Annual ASTM Symposium on Effects of Radiation on Materials, Denver, Colorado, June 21–22, 1992:

D. J. ALEXANDER, "The Effect of Irradiation on the Mechanical Properties of 6061-T651 Aluminum"

T. D. BURCHELL,* W. P. EATHERLY, AND J. P. STRIZAK, "The Effect of Neutron Irradiation on the Structure and Properties of Carbon-Carbon Composite Materials"

F. M. HAGGAG* AND R. K. NANSTAD, "Degradation of Mechanical Properties of Stainless Steel Cladding Due to Neutron Irradiation and Thermal Aging"

F. M. HAGGAG* AND R. K. NANSTAD, "Irradiation Temperature Effects on Embrittlement of Nuclear Pressure Vessel Steels"

R. L. KLUEH,* D. J. ALEXANDER, AND P. J. MAZIASZ, "Effect of Microstructure on Impact Properties of Irradiated 9Cr-1MoVNb and 12Cr-1MoVW Steels"

L. K. MANSUR,* E. H. LEE, M. B. LEWIS, AND S. J. ZINKLE, "Multiple-Ion Irradiations: Facility Review and Highlights of Applications to Metals, Ceramics, and Polymers"

M. K. MILLER* AND M. G. BURKE, "An APFIM Survey of Grain Boundary Segregation and Precipitation in Irradiated Pressure Vessel Steels"

R. K. NANSTAD* AND R. G. BERGGREN, "Irradiation Effects on Charpy Impact and Tensile Properties of Low Upper-Shelf Welds, Heavy-Section Steel Irradiation Program Series 2 and 3"

R. E. STOLLER, "Modeling the Influence of Irradiation Temperature and Displacement Rate on Hardening Due to Point Defect Clusters and Ferritic Steels"

R. E. STOLLER, "The Influence of Damage Rate and Irradiation Temperature on Radiation-Induced Embrittlement in Pressure Vessel Steels"

P. F. TORTORELLI* AND J. R. KEISER, "The Measurement of the Mechanical Properties of Oxide Scales by Submicron Indentation Testing"

C. A. WANG, M. L. GROSSBECK,* AND B. A. CHIN, "Technique to Eliminate Helium-Induced Weld Cracking in Stainless Steel"

C. A. WANG, H. T. LIN, M. L. GROSSBECK,* AND B. A. CHIN, "Threshold Helium Concentrations Required to Initiate Cracking During Welding of Irradiated Stainless Steel"

J. R. WEEKS, C. J. CZAJKOWSKI, M. K. KASSIR, AND K. FARRELL,* "Materials Surveillance for HFBR Beam Tube Integrity"

S. J. ZINKLE,* A. HORSEWELL, B. N. SINGH, AND W. F. SOMMER, "Microstructure of Copper Alloys Following 750 MeV Proton Irradiation"

6th International Conference on Intergranular and Interphase Boundaries in Materials (iib92), Thessaloniki, Greece, June 21-25, 1992:

E. D. SPECHT* AND F. J. WALKER, "Determination of the Chemical Valence of Atoms at a Heterophase Interface by X-Ray Diffraction Measurements of Crystal Truncation Rod Intensity at an Atomic Absorption Edge"

NATO Advanced Study Institute on Statics and Dynamics of Alloy Phase Transformations, Rhodes, Greece, June 21–30, 1992:

J. S. FAULKNER, E. A. HORVATH, Y. WANG, AND G. M. STOCKS,* "The Direct Monte Carlo Method for Calculating Alloy Phases"

G. M. STOCKS, "Electronic Theory of Order-Disorder Phenomena in Metallic Alloys"

CARBON '92, International Conference on Carbon, Essen, Germany, June 22-26, 1992:

T. D. BURCHELL, W. P. EATHERLY,* AND G. E. NELSON, "Radiation Damage in Carbon-Carbon Composites"

E. L. FULLER, JR., "Chemistry and Structure of Coals: Spectroscopic Evaluation of Hydrogenous Species"

E. L. FULLER, JR.,* O. C. KOPP, AND A. D. UNDERWOOD, "Gravimetric Measurements of the Kinetics and Mechanisms of Air Oxidation of Commercial Graphites"

The Third International Conference on Aluminum Alloys: Their Physical and Mechanical Properties, Trondheim, Norway, June 22-26, 1992:

T. L. JENNINGS, JR., T. H. SANDERS, JR.,* AND T. J. HENSON, "Ingot Homogenization"

First Pacific Rim International Conference on Advanced Materials and Processing, Hangzhou, China, June 23-27, 1992:

J. A. HORTON, "Ductility and Fracture in $L1_2$ Intermetallic Alloys"

J. A. HORTON,* C. T. LIU, E. P. GEORGE, Z. L. WANG, AND J. H. SCHNEIBEL, "Why are Many $L1_2$ Intermetallics Brittle?"

International Superconductivity Technology Center (ISTEC) Workshop, Honolulu, Hawaii, June 23-26, 1992:

D. M. KROEGER,* H. S. HSU, J. BRYNESTAD, V. K. SIKKA, T. WARD, AND T. KODAS, "Fabrication, Processing, and Properties of Powder-in-Tube Conductors Containing Bi(Pb)2223 Powder Prepared by Aerosol Pyrolysis"

First ORNL/UT Workshop on Coherent Beam Electron Microscopy, Knoxville, Tennessee, June 25-26, 1992:

L. F. ALLARD* AND T. A. NOLAN, "Optical Characteristics of Field Emission TEMS"

J. BENTLEY,* E. A. KENIK, Z. L. WANG, K. B. ALEXANDER, K. L. MORE, AND A. T. FISHER, "Materials Science Applications of an FEG-AEM"

Smoky Mountain Orchid Society Meeting, Knoxville, Tennessee, June 25, 1992:

R. J. LAUF, "Orchid Genetics and Breeding"

International Conference on Advances in Corrosion and Protection, University of Manchester Institute of Science and Technology (UMIST), Manchester, England, June 28–July 3, 1992:

J. H. DEVAN* AND P. F. TORTORELLI, "Oxidation-Sulfidation Behavior of Iron Alloys Containing 16 to 40 Atomic Percent Aluminum"

J. H. DEVAN* AND P. F. TORTORELLI, "Oxidation/Sulfidation Behavior of Iron Alloys Containing 15–40 Atomic Percent Aluminum"

6th International Conference on Solid Films and Surfaces, Paris, France, June 28–July 3, 1992:

R. A. MCKEE* AND F. J. WALKER, "MBE Growth and Heteroepitaxy in the Alkaline Earth Oxides"

24th ASTM National Symposium on Fracture Mechanics, Gatlinburg, Tennessee, June 30–July 2, 1992:

D. E. MCCABE,* J. G. MERKLE, AND R. K. NANSTAD, "A Perspective on Transition Temperature and K_{Jc} Data Characterization"

Lectures at the Institute of Electronic Structure and Lasers and the University of Crete Summer School, Heraklion, Crete, Greece, July 2–3, 1992:

W. H. BUTLER, "Multiple Scattering Theory"

NATO Advanced Study Institute on Mechanical Properties and Deformation Behavior of Materials Having Ultra-Fine Microstructures, Praia do Porto Novo, Portugal, July 4–12, 1992:

W. C. OLIVER,* B. N. LUCAS, AND G. M. PHARR, "The Mechanical Characterization of Thin Films Using Indentation Experiments"

G. M. PHARR, D. S. HARDING, AND W. C. OLIVER, "Measurement of Fracture Toughness in Thin Films and Small Volumes Using Nanoindentation Methods"

MICRO 1991, London, England, July 7–11, 1992:

D. C. JOY,* X.-G. ZHANG, Y. ZHANG, T. HASHIMOTO, L. F. ALLARD, AND T. A. NOLAN, "Applications of Electron Holography to Materials Science"

23rd Annual Meeting of the Fine Particle Society, Las Vegas, Nevada, July 14–17, 1992:

A. BLEIER, "Characterization and Control of Particle Surface Chemistry in the Aqueous Processing of Al_2O_3-ZrO_2 Composites"

Society of Photo-Optical Instrumentation Engineers (SPIE) 1992 International Symposium on Optical Applied Science and Engineering, San Diego, California, July 19–24, 1992:

G. E. ICE* AND C. J. SPARKS, "Sagittal Crystal Focusing of Undulator Radiation with High Heat Load Inclined Crystals"

International Conference on Martensitic Transformations (ICOMAT-92), Monterey, California, July 20–24, 1992:

R. L. KLUEH* AND D. J. ALEXANDER, "Relationship of Bainitic Microstructure to Toughness in Cr-Mo and Cr-W Steels"

Seminars at the Beijing Laboratory of Electron Microscopy and the Electron Microscopy Laboratory at Central Iron and Steel Research Institute (CISRI), Beijing, China, July 27–28, 1992:

Z.-L. WANG AND J. BENTLEY, "Reflection Electron Microscopy"

Z.-L. WANG,* A. GOYAL, AND D. M. KROEGER, "Stacking Faults Near the Y_2BaCuO_5/$YBa_2Cu_3O_{7-x}$ Interface and its Effect on Flux-Pinning in Melt Textured $YBa_2Cu_3O_{7-x}$"

Eighth Annual Coal Preparation Utilization and Environmental Control Contractors' Conference, Pittsburgh, Pennsylvania, July 29, 1992:

V. J. TENNERY AND K. BREDER,* "Materials Support for HITAF"

38th Annual Denver X-Ray Conference, Denver, Colorado, July 31–August 4, 1992:

O. B. CAVIN* AND J. S. WOLF, "X-Ray Examination of Type 310S Stainless Steel During Its Oxidation in Air at 900°C"

C. R. HUBBARD,* S. A. DAVID, S. SPOONER, AND X.-L. WANG, "Non-Destructive Residual Stress Mapping Facilities at Oak Ridge National Laboratory"

C. R. HUBBARD,* R. A. NEWMAN, AND A. KNUDSEN, "High Speed, High Temperature XRD Data Collection Using a Position Sensitive Detector"

X.-L. WANG,* C. R. HUBBARD, K. B. ALEXANDER, P. F. BECHER, J. A. FERNANDEZ-BACA, AND S. SPOONER, "Neutron Diffraction Studies of the Residual Microstresses in ZrO_2/Al_2O_3 Ceramic Composites"

X.-L. WANG,* C. R. HUBBARD, K. B. ALEXANDER, P. F. BECHER, J. A. FERNANDEZ-BACA, AND S. SPOONER, "Neutron Diffraction Study of the Pseudo-Macro Residual Stresses in $ZrO_2\{CeO_2\}/Al_2O_3$ Ceramic Composites"

5th Asia-Pacific Electron Microscopy Conference, Beijing, China, August 1–6, 1992:

A. HOWIE,* M. L. LANZEROTTI, AND Z. L. WANG, "Incoherence Effects in Reflection Electron Microscopy"

Z. L. WANG, "Characterizing Materials by Phonon Scattered High-Energy Electrons"

Z. L. WANG* AND J. BENTLEY, "Imaging and Spectrometry of Bulk Crystal Surfaces and Surface Dynamical Processes at High Temperatures"

Z. L. WANG,* A. GOYAL, AND D. M. KROEGER, "Stacking Faults Near the $Y_2BaCuO_5/YBA_2Cu_3O_{7-x}$ Interface and Its Effect on Flux-Pinning in Melt Textured $YBa_2Cu_3O_{7-x}$"

25th Annual Convention of the International Metallographic Society, Denver, Colorado, August 2–5, 1992:

A. CHOUDHURY, "Chemical Characterization of Surfaces and Interfaces Using Auger and Photoelectron Spectroscopies"

A. CHOUDHURY,* C. D. LUNDIN, C. R. BROOKS, AND K. K. KHAN, "Scanning Auger Spectroscopy of Reheat Crack Surfaces of Cr-Mo and HSLA Steel Weld HAZs"

Coatings for Advanced Heat Engines Workshop, Monterey, California, August 2–7, 1992:

D. P. STINTON* AND D. W. GRAHAM, "Chemical Vapor Deposition of Ta_2O_5 Corrosion Resistant Coatings"

Gordon Conference on Foams, Plymouth, New Hampshire, August 3–7, 1992:

M. T. BOMBERG* AND D. W. YARBROUGH, "Factors Affecting Thermal Aging of Foam Insulations"

Technology Transfer Conference and Workshop on Nickel and Iron Aluminides, Oak Ridge, Tennessee, August 4–5, 1992:

N. C. COLE, "Overview of ORNL In-House and Subcontracted Programs on Iron Aluminides"

P. F. TORTORELLI,* J. H. DEVAN, AND U. K. ABDALI, "High Temperature Oxidation of Iron and Nickel Aluminides"

American Institute of Chemical Engineers (AIChE) 1992 Summer National Meeting, Minneapolis, Minnesota, August 9–12, 1992:

R. R. JUDKINS, D. E. FAIN,* AND G. E. ROETTGER, "Potential for CO_2 Removal with Inorganic Membranes"

American Crystallographic Association 1992 Annual Meeting, Pittsburgh, Pennsylvania, August 9–14, 1992:

C. R. HUBBARD* AND O. B. CAVIN, "High Temperature X-Ray Powder Diffraction Studies at a National User Facility"

C. J. SPARKS* AND G. E. ICE, "Anomalous Scattering in Separation of Atom Pair Correlations in Crystalline Solid Solutions"

39th International Field Emission Symposium, Halifax, Canada, August 10–14, 1992:

K. O. BOWMAN, L. R. SHENTON, AND M. K. MILLER,* "The Use of Moment Estimators to Determine the Parameters of Concentration Fluctuations in Random Area Atom Probe Analyses"

R. JAYARAM* AND M. K. MILLER, "An AEM/APFIM Investigation of Precipitates in Model Vanadium Alloys"

R. JAYARAM* AND M. K. MILLER, "An Atom Probe/TEM Characterization of Carbon-Doped NiAl"

R. JAYARAM,* K. F. RUSSELL, AND M. K. MILLER, "An Atom Probe Study of the Substitutional Behavior of Beryllium in NiAl"

M. K. MILLER, "An Atom Probe Characterization of Isotopically-Tailored Fe-Cu Model Alloys"

M. K. MILLER,* K. O. BOWMAN, A. CEREZO, AND J. M. HYDE, "Comparison of Models for Deconvoluting the Compositions of Coexisting Phases"

M. K. MILLER* AND M. G. BURKE, "An APFIM/AEM Characterization of Alloy X750"

M. K. MILLER* AND R. JAYARAM, "Characterization of a $\Sigma 9$ Grain Boundary in Fe-45% Cr"

M. K. MILLER,* K. F. RUSSELL, L. C. EMERSON, K. W. BOLING, AND R. JAYARAM, "The ORNL Energy-Compensated Reflectron Atom Probe Field Ion Microscope"

European Synchrotron Radiation Facility (ESRF) Seminar, Grenoble, France, August 12–13, 1992:

G. E. ICE* AND C. J. SPARKS, "Sagittal Focusing with Bent Crystal Optics"

G. E. ICE,* C. J. SPARKS, AND L. B. SHAFFER, "Chemical and Displacement Atomic Pair Correlations in Crystalline Solid Solutions Recovered by Anomalous X-Ray Scattering"

Grain Boundary Chemistry and Brittle Fracture of Ordered Intermetallics Seminar, Auburn, Alabama, August 14, 1992:

E. P. GEORGE, "Grain Boundary Chemistry and Brittle Fracture of Ordered Intermetallics"

50th Annual Meeting of the Electron Microscopy Society of America (EMSA), Boston, Massachusetts, August 16–21, 1992:

K. B. ALEXANDER,* H. T. LIN, AND P. F. BECHER, "The Role of Electron Microscopy in the Development of Ceramic Composites"

L. F. ALLARD,* T. A. NOLAN, D. C. JOY, AND T. HASHIMOTO, "Digital Imaging for High-Resolution Electron Holography"

I. M. ANDERSON, "Crystal Orientation Effects in the X-Ray Microanalysis of Spinels"

D. C. PAINE,* D. J. HOWARD, AND N. D. EVANS, "In Situ TEM Studies of the Effect of Misfit Strain on the Kinetics of $Si_{1-x}Ge_x$ Solid Phase Epitaxy: Temperature Calibration and Surface Effects"

J. E. WITTIG,* N. QIU, AND N. D. EVANS, "Analytical Electron Microscopy of Rapidly Solidified Pt-Co-B Alloys"

AUSTCERAM '92 International Ceramics Conference and Exhibition, Melbourne, Australia, August 16–21, 1992:

T. N. TIEGS,* S. D. NUNN, P. A. MENCHHOFER, AND J. O. KIGGANS, JR., "Microstructural Development and Mechanical Properties of Gas-Pressure-Sintered Si_3N_4 With Refractory Grain Boundary Phases"

Presentation at Pratt and Whitney on Cooperative Research and Development Agreements (CRADAs), West Palm Beach, Florida, August 17, 1992:

C. T. LIU, "Alloy Design of Ordered Intermetallic Alloys"

International Conference on Anomalous Scattering (ICAS), Malente, Germany, August 17–21, 1992:

G. E. ICE* AND C. J. SPARKS, "Pair Correlations in Crystalline Solid Solutions"

F. J. WALKER* AND E. D. SPECHT, "Anomalous Crystal Truncation Rod Intensity: A Chemical and Structural Probe for Buried Interfaces"

1992 Annual Meeting of the Gear Research Institute, Detroit, Michigan, August 27, 1992:

G. M. LUDTKA,* K. W. CHILDS, G. A. ARAMAYO, K. H. LUK, AND J. E. PARK, "Computer Simulation of the Effects of Heat Treatment and Uniaxial Compression on the Residual Stresses in a Uranium-0.8 Weight Percent Titanium Alloy: Analytical Predictions and Experimental Verification"

Advanced Light Source (ALS) Users Meeting, Lawrence Berkeley Laboratory, Berkeley, California, August 27–28, 1992:

G. E. ICE* AND C. J. SPARKS, "Bend Magnet Microprobe Beam Line"

European Research Conference on Plasticity of Materials: Fundamental Aspects of Dislocation Interactions, Ascona, Switzerland, August 30–September 4, 1992:

M. H. YOO, "Anisotropic Coupling Effect on Dislocation Mobility: An Application to Crack-Tip Deformation"

Structural Properties of Carbons Conference, Carbondale, Illinois, August 31–September 4, 1992:

E. L. FULLER, JR.,* O. C. KOPP, AND A. D. UNDERWOOD, "Evaluation of Surface Structure and Chemistry of Graphites"

Third International Conference on The New Diamond Science and Technology (jointly with Diamond Films '92: Third European Conference on Diamond, Diamond-like and Related Coatings), Heidelberg, Germany, August 31–September 4, 1992:

R. E. CLAUSING,* L. HEATHERLY, T. THUNDAT, Z. L. WANG, AND T. KREUTZ, "Structural Aspects of Diamond Film Growth on {100} Surfaces"

T. KREUTZ,* R. E. CLAUSING, L. HEATHERLY, R. J. WARMACK, AND C. S. FEIGERLE, "Scanning Tunneling Microscopy of Boron-Doped CVD Diamond Films"

K. G. TSCHERSICH, R. E. CLAUSING,* AND L. HEATHERLY, "Surface Sensitive Characterization of Diamond by Ionization Electron Energy Loss Spectroscopy"

American Iron and Steel Institute (AISI) Committee on Technology, Pittsburgh, Pennsylvania, September 9, 1992:

H. W. HAYDEN, "Materials for Lightweight Vehicles Program, Lightweight Materials for Transportation System"

Meeting to Advocate Future Projects Funded by NASA, Huntsville, Alabama, September 9, 1992:

M. L. GROSSBECK, "Effects of Neutron Irradiation on Metals and Alloys"

Seminar at Technisch Universität Hamburg-Harburg (TUHH), Hamburg, Germany, September 14, 1992:

M. H. YOO, "Deformation and Fracture of Intermetallics: Fundamentals"

Third Annual U.S.S.R. Nuclear Society Meeting, St. Petersburg, Russia, September 14–18, 1992:

E. E. BLOOM AND A. F. ROWCLIFFE,* "Advanced Materials—The Key to Attractive Magnetic Fusion Power Reactors"

Seminar at GKSS-Research Center, Hamburg, Germany, September 15, 1992:

M. H. YOO, "Deformation and Fracture of Intermetallics: Fundamentals"

Sixth Annual Conference on Superconductivity and Applications, State University of New York at Buffalo, Buffalo, New York, September 15–17, 1992:

G. A. WHITLOW,* W. R. LOVIC, J. C. BOWKER, D. M. KROEGER, AND F. A. LIST, "High Critical Current Silver—$Bi_2Sr_2Ca_1Cu_2O_{8-x}$ Superconducting Multilayer Ribbons Produced by Rolling"

Seminar at Carnegie Mellon University, Pittsburgh, Pennsylvania, September 15, 1992:

P. F. BECHER, "Design of Reinforced Ceramics"

Seminar at Max-Planck-Institut für Eisenforschung, Düsseldorf, Germany, September 17, 1992:

M. H. YOO, "Deformation and Fracture of Intermetallics: Fundamentals"

Seminar at Forschungszentrum, KFA, Jülich, Germany, September 18, 1992:

M. H. YOO, "Deformation and Fracture of Intermetallics: Fundamentals"

National Steering Committee for an Advanced Neutron Source, U.S. Department of Energy, Washington, D.C., September 18, 1992:

E. E. BLOOM, "Radiation Effects and Materials Development"

International Symposium on Superalloys, Champion, Pennsylvania, September 20-24, 1992:

V. K. SIKKA, R. L. HEESTAND, AND E. A. LORIA,* "Preliminary Results of Processing and Properties of Nb-Ti-Based Alloys"

Optical Society of America Annual Meeting, Albuquerque, New Mexico, September 20-25, 1992:

J. M. MCNEELY,* M. A. AKERMAN, R. E. CLAUSING, M. B. MCINTOSH, W. B. SNYDER, JR., AND M. E. THOMAS, "High Temperature Optical Characterization of CVD Diamond"

J. M. MCNEELY,* M. THOMAS, R. E. CLAUSING, A. K. AKERMANN, AND W. SNYDER, "Elevated Temperature Optical Properties of CVD Diamond"

Second National Conference on Materials Science, Cancun, Mexico, September 20-25, 1992:

J. H. SCHNEIBEL, "Ductility and Toughness of Intermetallics"

International Energy Agency (IEA) Workshop on Intense Neutron Sources, Kernforschungszentrum Karlsruhe (KfK) Nuclear Research Center, Karlsruhe, Germany, September 21-23, 1992:

E. E. BLOOM, "Materials Development for DEMO and Commercial Fusion Reactors"

Seminar at Max-Planck-Institut für Metallforschung, Stuttgart, Germany, September 21, 1992:

M. H. YOO, "Deformation and Fracture of Intermetallics: Fundamentals"

IX International Conference on Ion Implantation Technology, Gainesville, Florida, September 21-24, 1992:

E. H. LEE,* M. B. LEWIS, AND L. K. MANSUR, "Ion Beam Application for Improved Polymer Surface Properties"

Purdue Graduate Seminar, West Lafayette, Indiana, September 21, 1992:

J. O. KIGGANS, JR.,* AND T. N. TIEGS, "Microwave Processing of Ceramics at Oak Ridge National Laboratory"

Second International Conference on Computer Applications to Materials and Molecular Science and Engineering (CAMSE '92), Yokohama, Japan, September 22-24, 1992:

C. T. LIU* AND C. L. FU, "Alloy Design of Ordered Intermetallic Alloys"

The Effect of Irradiation on Materials of Fusion Reactors Conference, St. Petersburg, Russia, September 22-24, 1992:

E. V. NESTEROVA,* V. V. RYBIN, S. J. ZINKLE, V. R. BARABASH, AND A. V. NABERENKOV, "Ion Irradiation Induced Subgrain Structure Formation in Dispersion Strengthened Copper Alloys"

S. J. ZINKLE AND A. F. ROWCLIFFE,* "Ceramics Radiation Effects Issues for ITER"

S. J. ZINKLE, E. V. NESTEROVA, V. V. BARABASH,* V. V. RYBIN, AND A. V. NABERENKOV, "Structural Stability of MAGT and GLIDCOP Dispersion Strengthened Copper Alloys Under Ion Irradiation"

Presentation at the Colorado School of Mines, Golden, Colorado, September 24, 1992:

J. M. VITEK, "Non-Equilibrium Solidification in Stainless Steels"

U.S.-Russia Working Group 3 Meeting of the Joint Coordinating Committee for Civilian Nuclear Reactor Safety (JCCCNRS), St. Petersburg and Moscow, Russia, September 24-October 2, 1992:

R. K. NANSTAD, "Charpy Impact Testing for JCCCNRS Working Group 3 Round-Robin Program"

R. K. NANSTAD* AND S. K. ISKANDER, "Effects of Irradiation on K_{Ic} and K_{Ia} Curves for Two High-Copper Submerged-Arc Welds"

G. R. ODETTE, R. E. STOLLER, AND R. K. NANSTAD,* "Summary of Recent Investigations Regarding Radiation Damage Mechanisms in Reactor Vessel Steels"

HTML Users Group Meeting, September 25, 1992:

C. R. HUBBARD* AND X.-L. WANG, "Summary of Research in the New Residual Stress User Center"

1992 International CFC and Halon Alternatives Conference, Washington, D.C., September 29-October 1, 1992:

T. G. KOLLIE,* R. S. GRAVES, K. W. CHILDS, AND F. J. WEAVER, "Recent R&D Results on Vacuum Super-Insulation at the Oak Ridge National Laboratory"

Evolution of Microstructure in Metals During Irradiation Conference, Chaulk River Laboratories, Ontario, Canada, September 29–October 2, 1992:

M. G. BURKE* AND M. K. MILLER, "A Study of Radiation-Induced Microstructural Features in Reactor Pressure Vessel Steels"

F. A. GARNER,* N. SEKIMURA, M. L. GROSSBECK, AND M. KIRITANI, "Unanticipated Influence of Details of Reactor History on Microstructural Development During Neutron Irradiation"

E. A. KENIK, "Elemental Inhomogeneities Developed in Stainless Steels by Radiation-Induced Segregation"

P. J. MAZIASZ, "An Overview of Microstructural Evolution and its Effects on Properties in Neutron-Irradiated Austenitic Stainless Steels"

Institute for Defense Analyses (IDA) Carbon-Carbon Technical Exchange Conference, Washington, D.C., September 29–30, 1992:

R. L. BEATTY, "Advanced Materials and Processing Technologies at DOE's Oak Ridge Complex"

W. P. EATHERLY, "Irradiation Effects on C-C Composites for Fusion-Energy Applications"

W. P. EATHERLY, "Thermal and Mechanical Properties of C-C Based Composites for Thermal Insulators (CBCF)"

G. R. ROMANOSKI, "Development of Graphite Impact Shell for Radioisotope Space Power Systems"

J. P. STRIZAK, T. D. BURCHELL, AND G. R. ROMANOSKI,* "New Production Reactor Control Rod Structure"

C. E. WEAVER, "Manufacture of Carbon Bonded Carbon Fiber Thermal Insulators for Radioisotope Space Power Systems"

14th International Conference on Plasma Physics and Controlled Nuclear Fusion Research, Wurzburg, Germany, September 30–October 7, 1992:

D. L. SMITH,* E. E. BLOOM, D. G. DORAN, R. H. JONES, A. F. ROWCLIFFE, AND F. W. WIFFEN, "Reduced Activation Structural Materials Development for Demo Fusion Reactor Applications"

Advanced Workshop on Whiskers and Particles in Composite Materials Technology, International Center for Theoretical Physics, Trieste, Italy, October 5–9, 1992:

P. F. BECHER,* K. B. ALEXANDER, C. H. HSUEH, H. T. LIN, T. N. TIEGS, AND W. H. WARWICK, "The Design and Properties of Ceramics Reinforced by Whiskers and Similar Microstructural Features"

Japan Institute of Metals (JIM) Fall Meeting, Toyama, Japan, October 6–8, 1992:

C. NISHIMURA* AND C. T. LIU, "Effects of Alloy Composition on Environmental Embrittlement in $L1_2$-Ordered $(Co,Fe)_3V$ Alloys"

15th Annual DOE/BES Welding Science Contractors Meeting, Pennsylvania State University, University Park, Pennsylvania, October 8–9, 1992:

C. R. HUBBARD* AND X.-L. WANG, "Summary of Research in the New Residual Stress User Center"

Fourth AIST-NEDO/DOE-HQ Joint Technical Meeting on Materials for Coal Liquefaction, San Francisco, California, October 12, 1992:

R. R. JUDKINS, "DOE Fossil Energy Advanced Research and Technology Development Materials Program"

R. R. JUDKINS* AND S. WASAKA, "Tests of Nickel Aluminide for Coal Liquefaction Letdown Valves"

J. R. KEISER* AND T. J. HENSON, "Examination of Japanese Samples Exposed in the Wilsonville Liquefaction Reactors"

Meeting at General Motors Corporation, Warren, Michigan, October 14, 1992:

C. T. LIU, "Intermetallic Alloys and Reaction Synthesis"

Workshop on the Time Dependence of Radiation Damage Accumulation and Its Impact on Materials Properties, Montreaux, Switzerland, October 14–20, 1992:

L. K. MANSUR, "Theory and Mechanisms of Transitions in Dose Dependence of Radiation Effects in Materials"

1992 VIM, VAR, and ESR Experience Seminar, Hilton Head, South Carolina, October 19–21, 1992:

T. J. HUXFORD, "Operation of a Pilot-Scale Vacuum-Arc-Remelt Furnace"

TechEx '92 Conference, Pittsburgh, Pennsylvania, October 20–22, 1992:

J. R. WEIR, JR., "Technology Transfer: From Washington to in the Trenches"

20th Water Reactor Safety Information Meeting, Bethesda, Maryland, October 21–23, 1992:

W. R. CORWIN, "Managing Irradiation Embrittlement in Aging Reactor Pressure Vessels"

C. V. DODD,* J. R. PATE, AND J. D. ALLEN, JR., "Advancement in Eddy-Current Test Technology for Steam Generator Tube Inspection"

K. FARRELL,* S. T. MAHMOOD, R. E. STOLLER, AND L. K. MANSUR, "Investigations of Low Temperature Neutron Embrittlement of Ferritic Steels"

Second JAERI Symposium on HTGR Technologies, Oarai, Japan, October 21–23, 1992:

M. J. KANIA,* R. C. MARTIN, R. N. MORRIS, J. T. PARKS, O. F. KIMBALL, AND R. F. TURNER, "Fuel Technology Program Activities in the U.S. Supporting the Modular High Temperature Reactor"

1992 John K. Tien Memorial Conference on Electron Beam Melting and Refining, Reno, Nevada, October 25–27, 1992:

T. J. HUXFORD, "Electron Beam Processing of Kg Quantities of Iridium for Radioisotope Generator Applications"

T. J. HUXFORD* AND E. K. OHRINER, "Electron-Beam Processing of Kilogram Quantities of Iridium for Radioisotope Thermoelectric Generator Applications"

International Conference on Design and Safety of Advanced Nuclear Power Plants (ANP '92), Tokyo, Japan, October 25–29, 1992:

M. J. KANIA,* C. A. BALDWIN, G. L. BELL, L. C. EMERSON, W. A. GABBARD, R. N. MORRIS, N. H. PACKAN, J. T. PARKS, AND K. R. THOMS, "Coated Particle Fuel Performance Under Normal and Accident Conditions"

ASM Materials Week, Chicago, Illinois, October 26–28, 1992:

D. P. POPE,* E. P. GEORGE, AND V. SKLENICKA, "The Effects of Trace Impurities on Creep Fracture in Steels"

International Energy Agency (IEA) Workshop on Ferritic/Martensitic Steels for Fusion, Tokyo, Japan, October 26–28, 1992:

R. L. KLUEH, "Alloy Development Philosophy in the USA"

R. L. KLUEH, "Irradiation Effects on Mechanical Properties: U.S. Studies"

R. L. KLUEH* AND P. F. TORTORELLI, "Compatibility of Ferritic/Martensitic with Coolants and Breeding Materials: The U.S. Program"

Air Force Office of Scientific Research (AFOSR) Ceramics and Glass Contractors' Conference, National Academy of Sciences, Washington, D.C., October 28–29, 1992:

T. M. BESMANN,* B. M. GALLOIS, M. A. AKERMAN, AND R. A. LOWDEN, "Nucleation and Growth of Silicon Carbide on Silicon and Composite Coatings for Carbon/Carbon Protection"

Technical Seminar, Pennsylvania State University, University Park, Pennsylvania, October 29, 1992:

L. F. ALLARD, "Electron Holography: Techniques and Perspectives for Materials Science"

45th American Ceramic Society (ACerS) Pacific Coast Regional Meeting, San Francisco, California, November 1–4, 1992:

M. K. FERBER* AND M. G. JENKINS, "Creep and Fatigue Behavior of a HIPed Silicon Nitride"

C.-H. HSUEH, "A Simple Treatment of Poisson's Effect for Fiber Push/Pull Tests"

H.-T. LIN,* P. F. BECHER, AND T. N. TIEGS, "High Temperature Creep of Self-Reinforced Si_3N_4 Ceramics"

A. J. MOORHEAD, "Ceramic/Ceramic Joints Brazed with Active Filler Metals"

S. D. NUNN,* T. N. TIEGS, AND P. A. MENCHHOFER, "In Situ Toughened Si_3N_4 Containing Refractory Grain Boundary Phases"

J. H. SCHNEIBEL* AND P. M. HAZZLEDINE, "Cobble Creep in Irregular Microstructures"

T. N. TIEGS,* J. O. KIGGANS, JR., K. L. PLOETZ, AND C. E. HOLCOMBE, "Silicon Nitride From MARS"

1992 TMS/AIME Fall Meeting, Chicago, Illinois, November 1–5, 1992:

D. J. ALEXANDER,* K. B. ALEXANDER, AND R. K. NANSTAD, "The Effects of Aging at 343°C on the Mechanical Properties and Microstructure of Type 308 Stainless Steel Weld Metal"

D. J. ALEXANDER,* P. J. MAZIASZ, AND C. R. BRINKMAN, "The Effect of Long-Term Aging on the Impact Properties of Modified 9Cr–1Mo Steel"

D. J. ALEXANDER* AND V. K. SIKKA, "Fracture Behavior of Iron Aluminide Alloys"

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University of Salt Lake City, Department of Materials Science Seminar, Salt Lake City, Utah, November 23, 1992:

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Nuclear Electric Seminar, Berkeley Nuclear Laboratories, Berkeley, United Kingdom, November 23, 1992:

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ASTM Symposium on Wear Test Selection for Design and Applications, Miami, Florida, December 9, 1992:

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