Survey and Analysis of Materials Research and Development at Selected Federal Laboratories

N. L. Moore, Project Manager

April 1984

**Prepared by Energetics, Inc.
for Pacific Northwest Laboratory
under Contract DE-AC06-76RLO 1830
with the U.S. Department of Energy**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

NTIS Price Codes
Microfiche A01

Printed Copy

Pages	Price Codes
001-025	A02
026-050	A03
051-075	A04
076-100	A05
101-125	A06
126-150	A07
151-175	A08
176-200	A09
201-225	A010
226-250	A011
251-275	A012
276-300	A013

SURVEY AND ANALYSIS OF MATERIALS
RESEARCH AND DEVELOPMENT AT
SELECTED FEDERAL LABORATORIES

J. E. Reed
C. R. Fink

Energetics, Inc.
Columbia, Maryland

N. L. Moore, PNL Project Manager

April 1984

Prepared by Energetics, Inc.
for Pacific Northwest Laboratory
under Contract DE-AC06-76RLO 1830
with the U.S. Department of Energy
under Agreement B-D2028-A-Z

Pacific Northwest Laboratory
Richland, Washington 99352

EXECUTIVE SUMMARY

BACKGROUND

Federal laboratories represent collections of expertise and facilities unparalleled in the world. They conduct basic and applied research and development (R&D) in numerous and diverse fields. Although the products of their efforts could be of considerable value to the private sector, they may remain relatively unknown due to the time and resources required to identify and analyze them.

This document presents the results of an effort to transfer existing, but relatively unknown, materials R&D from selected federal laboratories to industry. More specifically, recent materials-related work at seven federal laboratories potentially applicable to improving process energy efficiency and overall productivity in six energy-intensive manufacturing industries was evaluated, catalogued, and distributed to industry representatives to gauge their reaction.

Laboratories surveyed include: Air Force Wright Aeronautical Laboratories Material Laboratory (AFWAL), Pacific Northwest Laboratory (PNL), National Aeronautics and Space Administration Marshall Flight Center (NASA Marshall), Oak Ridge National Laboratory (ORNL), Brookhaven National Laboratory (BNL), Idaho National Engineering Laboratory (INEL), and Jet Propulsion Laboratory (JPL). Industries included in the effort are: aluminum, cement, paper and allied products, petroleum, steel and textiles.

METHODOLOGY

The principal steps in this effort were to:

- 1) develop taxonomies of the six energy-intensive manufacturing industries,
- 2) identify opportunities for improving process energy efficiency and productivity as well as laboratory capabilities and special technical expertise,
- 3) contact laboratories through visits or other forms of inquiry,
- 4) review R&D findings with industry, and
- 5) evaluate and compile industry responses.

Four of the seven laboratories surveyed (AFWAL, PNL, NASA Marshall, and ORNL) were visited to obtain information, and the remaining three (BNL, INEL and JPL) were queried by telephone and written communication.

Taxonomies were developed for manufacturing industries, describing the major processes and activities from raw material acquisition to completion of the manufactured goods. The taxonomies provide a means of coupling federal materials R&D with identified opportunities for improving energy efficiency and productivity of industrial processes. They also enable industry personnel to readily identify federally-developed technologies applicable to particular sectors of the industry.

Prior to the lab visits or other inquiries, major program efforts, unique technical expertise, and existing technology transfer efforts at the selected federal labs were identified. In addition, the project team convened brainstorming sessions during which industry needs and possible laboratory programs applicable to those needs were postulated. The document from this session (a taxonomy on which was overlaid the team's perceptions of federal laboratory work potentially applicable to individual elements) was sent to the laboratories to provide advanced insight into the scope and depth of the investigation.

The laboratory visits typically involved an initial presentation to a small group of senior technical managers selected by the technology utilization officers. Principal investigators working in areas related to the taxonomy elements, identified in the initial presentation, were then interviewed. The resulting notes and technical documents became the information base for the project. Labs queried, but not visited, were treated in an analogous manner. After obtaining names and telephone numbers from the technology utilization officers, research management personnel and/or appropriate principal investigators were contacted by telephone or letter to obtain information on applicable R&D efforts.

Follow-up activities included the cataloging of information gathered, additional communications with the principal investigators, and the development of formatted profiles for each technology. The technology profiles were compiled in notebook form, arranged by taxonomy element, and distributed to industry

personnel for review and comment. Finally, industry comments were compiled to develop a summary of industry reaction.

RESULTS

Numerous federally-developed technologies were identified during the course of this effort. Profiles for 56 technologies relevant to six manufacturing industries were prepared and are presented in Section 4.0 of this document. Presented below are summary descriptions of federal R&D efforts potentially applicable to each of the manufacturing industries.

Aluminum

Aluminum production processes ranging from raw material acquisition to fabrication of aluminum products could potentially benefit from federal materials R&D. For example, surface science techniques developed by PNL could improve the processing of bauxite and could conceivably play a role in the recovery of aluminum from other, more plentiful, mineral deposits. Raw material acquisition and processing operations involving grinding and rotating industrial equipment could benefit from erosion-resistant materials and improved bearing and lubricating systems. Examples of the former are sputter deposition coating work at PNL and work on corrosion/erosion-resistant coatings and amorphous metals at ORNL. Examples of the latter are NASA Marshall's experimental data base on bearings and lubricants and ORNL's computer-accessible system for retrieval of tribological design data.

A number of federal R&D efforts relating to improved structural materials and materials/facilities for energy conservation and recovery are applicable to aluminum smelting, alloying and fabrication operations. For example, ORNL is investigating long-range ordered and ordered intermetallic alloys for high-temperature structural applications that could be used in place of austenitic stainless steels or superalloys that contain costly strategic metals. INEL's study of the effect of coal gasification atmospheres on the biaxial creep of alloys and its mechanical properties design data for 718 stainless might also be of interest to the aluminum industry.

Ceramics R&D at the various labs may have application in the aluminum industry. ORNL is examining the fabrication and use of TiB_2 ceramics for cutting tools, as valve trim in erosive environments, and of most importance to the aluminum industry, as cathodes in Hall-Heroult cells. ORNL is also exploring techniques for joining of ceramics (to other ceramics and metals) for potential application in high-temperature heat exchangers. Similarly, INEL is studying the joining of silicon nitride-based ceramics. PNL is studying the interactions of refractory ceramic oxides with severe thermal, chemical, and electrochemical environments; this work is potentially applicable to improved refractories, refractory coatings on metals, and high-temperature recuperative or regenerative heat exchangers among other items.

Several R&D efforts have specific application to aluminum casting, alloying, and fabrication operations. NASA Marshall's materials processing in space activities (e.g., its study of alloy microsegregation behavior) could yield greater understanding of alloy solidification mechanisms and ultimately improve process control. AFWAL's research capabilities, particularly rapid-solidification-rate casting, could reduce metal losses while producing less costly, long lived and more efficient aluminum structures. Also of note, is AFWAL capability with superplastic forming of titanium and its research to acquire a similar capacity with aluminum-based materials. A focus of the effort is the forming of complex, unitized, honeycomb- and heat exchanger-like components. AFWAL has developed a computerized methodology to enhance productivity of die forging systems. Computer techniques are used to generate a streamlined die design and a forging process that will yield an improved product. Finally, various welding and machining innovations are being explored at several laboratories. Examples of welding research and development include:

PNL

- electroslog welding improvements,
- a remote welding device,
- novel spot welding techniques, and
- weld evaluation methodologies

NASA Marshall

- variable polarity plasma arc welding that can reduce precleaning requirements, reduce distortion and improve weld quality
- computer modeling/control of welding.

Other federal R&D programs applicable to the aluminum industry include:

- high-speed machining techniques for the milling of space shuttle external fuel tank panels (NASA Marshall),
- nondestructive evaluation research and facilities (AFWAL and PNL),
- the integrated computer-aided manufacturing program (AFWAL),
- high-temperature, high-pressure electrochemical probes (PNL),
- sensor research and development (ORNL),
- a stress corrosion testing program (NASA Marshall), and
- a study of the kinetics and mechanisms of alternative fuels and combustion (BNL).

Cement

Federal materials R&D applicable to the cement industry includes work relating to erosion-resistant materials/coatings and improved bearing and lubricating systems that could benefit quarrying and transportation systems, crushing and grinding operations, and final grinding operations. Examples are PNL's high-rate sputtering technology that could be used to lay down protective coatings as well as to form free-standing components, NASA Marshall's turbine blade coating work using a vacuum spray coating process, and ORNL's work with erosion-resistant coatings, based on chemical vapor-deposited titanium diboride as well as its ion implantation research and user's facility and its research on amorphous metals.

Examples of bearings and lubricants work are NASA Marshall's bearing tests data base and ORNL's computer-accessible system for the retrieval of tribological design data. Although not specifically related to bearings and lubricants, ORNL's trouble-shooting capability via noise analysis of rotating equipment may also be of value.

ORNL's industrial insulation, refractories, and recuperation experience and facilities along with NASA Marshall's capability in adhesive bonding (for attachment of insulation or refractories) may be of value to the pyroprocessing of raw materials in the cement kiln and associated processes (e.g., cooling) to produce clinker. PNL's study of electronically-conducting refractory oxides and of high-temperature corrosion and electrochemical interactions in ceramics could ultimately be relevant to developing improved refractories for some operations. ORNL's telemetering system for transmitting temperature profiles from a nuclear fuels processing (rotary) kiln could lead to improved control of cement kiln operations. Also potentially relevant to kiln operations, in light of increasing interest in firing refuse derived fuels, petroleum coke and other alternative fuels in the cement kiln, are BNL's research capabilities in the kinetics and mechanisms of alternative fuels combustion.

Laboratory efforts that may be applicable to improved process control in the cement industry include noise analysis and telemetering systems at ORNL, nondestructive evaluation techniques at AFWAL, high-temperature, high-pressure electrochemical probes developed at PNL, and AFWAL's integrated computer-aided manufacturing program. A procedure developed at PNL to optimize the design of multi-component mixtures to yield optimal material properties, using experimental design and statistical analysis techniques, could be very useful in optimizing mix designs for cement and concrete products.

Although not strictly related to cement manufacture, BNL has done much work on the properties and applications of specially formulated cement and concrete materials that should be of interest to those in the industry. Examples are the use of calcium silicate cement sorbent for H_2S removal and improved coal gasification processes, concrete polymer materials for overlays and patching materials, and development and evaluation of cements for geothermal well applications.

Paper

Federal R&D efforts were found to be potentially applicable to several activities in the pulp and paper industry. For example, a lightweight, helicopter-transportable fire fighting module developed by NASA Marshall could

be used for both fire fighting and emergency pumping in forest yield management. Technologies that yield improved wear-resistant surfaces and technologies that yield improved bearing and lubricating systems in equipment would benefit harvesting, debarking, chipping and mechanical pulping operations.

Examples of the former include:

- sputter deposition work (PNL),
- a turbine blade coating process based on vacuum plasma spray coating (NASA Marshall),
- research on TiB_2 ceramics including chemical vapor deposited TiB_2 (ORNL), and
- work with amorphous metals and ion implementation of both metals and ceramics (ORNL).

Examples of the latter include: a bearing tests data base maintained at NASA Marshall and a computer-accessible system for retrieval of tribological design data developed at ORNL.

Some of the same technologies applicable to harvesting, debarking, and chipping would also be applicable to pulping and bleaching, paper and paper-board production, and coating and converting. These may also apply to power and chemical recovery, particularly in the black liquor cycle. For example, amorphous coatings, made possible by work by ORNL, PNL and others, could be used to coat boiler tubes (inside and out) to obtain high-temperature capabilities as well as corrosion resistance. This could solve the corrosion problems encountered in the Tomlinson boiler. PNL's surface science techniques and instrumentation and BNL's corrosion research facilities could also yield understanding and resolution of corrosion problems in the paper industry.

The pulp and paper industry is a prime candidate for improved techniques and equipment for monitoring and control of unit processes and can potentially benefit from several federal R&D efforts. PNL has developed several high-temperature, high-pressure electrochemical probes that could be used to monitor process variables under harsh environments. PNL has also developed high electronically conducting refractory oxides that could be used in high-temperature sensors and meters useful for process control. Other related work is the

development of urethane coating and potting material by NASA Marshall, a wide range of sensors research and capabilities at ORNL, and an integrated computer-aided manufacturing program at AFWAL.

Finally, several important technologies were identified that were applicable to materials and energy recovery from waste streams and to pollution control in the paper industry. BNL is examining the kinetics and mechanisms of alternative fuels combustion including study of the effects of combustor operating conditions and fuel parameters on pollutant emission rates and combustion efficiency. Both ORNL and JPL have investigated bacterial fermentations using clostridia species to produce butanol or as a surfactant for tertiary oil recovery. Such fermentations could use cellulose and starch containing waste streams found in the paper industry as a feedstock. JPL's work on biocatalysis, catalyst modeling, and separation techniques could also be applicable to energy/material recovery and pollution control. ORNL's investigations of separations chemistry include study of dynamically formed membranes for reverse osmosis and ultrafiltration processes to treat paper industry wastewaters. JPL's power generation turbine for two-phase (gas/liquid) fluids in waste heat streams could be applied to waste streams in the paper industry.

Petroleum

A number of federally developed technologies were found to be potentially applicable to processes in the petroleum industry beginning with exploration, drilling and recovery, and crude oil transport.

Surface science techniques and instrumentation at PNL could conceivably assist in the discovery of oil and gas through surface analysis of geologic deposits. Sputter deposition coating at PNL could be used to produce erosion-resistant coatings for materials prone to wear during drilling and recovery operations. Similarly, chemical vapor deposited TiB_2 ceramics (ORNL) could provide an improved surface for drilling tools. ORNL's investigations of amorphous metals and NASA Marshall's vacuum plasma spray coating process used to coat turbine blades might also be relevant. A bearing tests data base maintained at NASA Marshall and a computer-accessible system for retrieval of

tribological design data developed by ORNL might help improve bearing and lubricating systems in rotating drilling equipment. BNL has developed and evaluated geothermal well cementing materials that should be useful for petroleum wells, particularly where high-temperature, saline and corrosive conditions are encountered. A power generation turbine for two-phase (gas/liquid) fluids, developed by JPL could be used for both separating natural gas from crude oil and for generating power near the well site.

Improved welding techniques developed at PNL, and variable polarity plasma arc welding and computer modeling/control of welding at NASA Marshall could be of interest with respect to the welding of oil pipelines.

Washing, separation, conversion and chemical treatment operations, which are similar in that they all can involve high-temperature, high-pressure vessels and reactors often subject to corrosive conditions, could benefit from federal R&D related to corrosion/erosion resistant materials/coatings and high-temperature structural materials.

Examples of development and evaluation of materials with improved temperature and/or corrosion resistance include:

- long-range ordered and ordered intermetallic alloys developed by ORNL that could replace some stainless steels and superalloys that contain costly strategic materials,
- structural ceramics based on TiB_2 ceramics also developed by ORNL,
- study of the effects of coal gasification atmospheres on biaxial creep of alloys by INEL, and
- the generation of mechanical properties design data for Alloy 718 stainless steel and Type 316 stainless steel by INEL.

PNL's studies of corrosion from the surface science discipline and BNL's corrosion research capabilities would both seem to be directly applicable to understanding and resolving corrosion problems in petroleum industry processes.

ORNL's expertise and facilities in the area of industrial insulation, refractories and recuperation and NASA Marshall's adhesive bonding capability

(for attachment of insulating or refractory materials) could minimize energy losses from process units and auxiliary equipment (e.g., piping). An area of study with potentially wide ranging applicability in the petroleum industry, especially for catalytic and separation processes, is JPL's fundamental work in biocatalysis, catalyst modeling and separation. PNL's surface science facilities could be of enormous utility in research of catalysis. PNL's procedures for optimizing the component proportions of multi-component mixtures to obtain desired properties might be effectively applied to some products of the petroleum industry. In a related area, ORNL's study of the lubricating qualities of base stock oils could be of value in the formulation of many petroleum-based lubricants.

Improved process monitoring and process control could result from the nondestructive evaluation (NDE) work and capabilities at AFWAL and PNL, high-temperature and high-pressure electrochemical probes developed at PNL, and the development of urethane coating and potting material at NASA Marshall.

Finally, health, safety, and pollution control activities in the petroleum industry can benefit from federal R&D. Some notable examples are: 1) NDE work of AFWAL and PNL, 2) pipe test facilities at PNL, 3) a large cable tester at PNL that could be applicable to drilling operations and for the mooring of drilling platforms via tension cables, 4) a stress corrosion testing program at NASA Marshall that includes data for nearly 50 different materials exposed to a sea coast atmosphere, and 5) a lightweight, helicopter-transportable fire fighting module, developed at NASA Marshall that could be used for both offshore fire fighting and oil spill clean-up. Some additional activities include: pollution control research at ORNL including specially filled activated carbons and dynamically formed membranes for reverse osmosis and ultrafiltration units, study of the kinetics and mechanisms of alternative fuels combustion and use of a calcium silicate cement sorbent for H_2S removal and improved coal gasification processes, both by BNL.

Steel

Because many of the unit operations in the various process elements of steel production involve high temperatures and potentially corrosive conditions, many of the same federal R&D efforts are relevant to several process

elements. Some of the more widely applicable R&D efforts relate to protecting materials against high temperatures, minimizing heat loss, or improving materials for process units and heat recovery devices. Additionally, there are several efforts that relate specifically to various casting and fabrication operations.

ORNL's facilities and expertise in industrial insulation, refractories, and recuperation can be used, for example, to test the effectiveness and behavior of various materials in fossil fuel combustion environments. NASA Marshall's capabilities in adhesive bonding could be of value in attachment of insulation and refractories.

A number of research efforts could lead to improved materials for high-temperature applications and/or applications where corrosion resistance is required, such as in heat exchangers. ORNL has developed long-range ordered and ordered intermetallic alloys for high-temperature structural applications. These materials are possible substitutes for austenitic stainless steels and superalloys without the use of costly strategic materials such as Co and Cr. ORNL has also examined TiB_2 -based ceramics as structural materials and has explored techniques for joining various ceramics to each other and to metals. INEL has examined the joining of SiN_4 ceramics as well. Study of the effect of coal gasification atmospheres on biaxial creep of alloys and generation of mechanical properties design data for selected stainless steels are other INEL activities of possible interest.

For understanding and resolving general or specific corrosion problems, BNL's corrosion research capabilities, PNL's surface science techniques and facilities, and NASA Marshall's stress corrosion testing program may be valuable.

Several important R&D efforts were identified that could benefit casting and fabrication operations. NASA Marshall is studying solidification characteristics of alloys, particularly microsegregation behavior, as a function of gravity. AFWAL has the capability for superplastic forming of titanium, particularly complex unitized components, and is working to acquire a similar capability with iron and aluminum-based materials. AFWAL has also developed a methodology for enhanced productivity of die forging systems, which, by using

computer-aided design and manufacturing, yields a streamlined die design and a forging process that can produce a superior product. Finally in this area, ORNL is developing suitable lubricants for warm forming of metals. Such lubricants, by operating in the warm forming range (400 to 800°F), can minimize energy consumed in extruding/rolling operations.

Other federal R&D efforts of potential interest to the steel industry include: nondestructive evaluation capabilities at AFWAL and PNL, PNL's surface science techniques as applied to catalysis and JPL's work in biocatalysis and catalyst modeling, both of which could be useful in low Btu gas combustion and BNL's expertise and facilities for studying the kinetics and mechanisms of alternative fuels combustion.

Textiles

The textile industry encompasses a wide spectrum of operations which produce a variety of end products. The equipment used in fiber acquisition and production, yarn making, fabric construction and fabric finishing typically involves moving parts often operating at high speeds. These operations can also involve the application of chemicals (dyes, sizing, bleach, etc.) and/or other treatments (drying, shearing, brushing, etc.) to obtain fabrics with specific properties. Three areas of federal material R&D seem to be particularly applicable to the textile industry: erosion/corrosion-resistant materials, improved bearing and lubricating systems and improved process control.

Erosion/corrosion-resistant materials and coatings that can lessen the wear of machinery parts in contact with each other or with the processed material could be of considerable value to the textile industry. ORNL's work on erosion-resistant coatings, (specifically, chemical vapor deposited TiB₂, amorphous metals R&D, and ion implantation research) and its user's facility may be helpful to the textile industry. Other potentially relevant work includes: the sputter deposition coating capability at PNL and the vacuum plasma spray coating process used at NASA Marshall for coating of turbine blades. Also related to wear of parts, materials life prediction methodology developed at AFWAL could be applicable to certain costly machinery parts.

Improved bearing and lubricating systems is the second area of particular applicability. Specifically, NASA Marshall's bearing tests data base, which includes information on such parameters as coefficients of friction between many different materials, different loads, different surface finishes, and different lubricants under specific loads and environments should be applicable. Also, ORNL's computer-accessible system for retrieval of tribological design data should be of use to designers of textile industry equipment.

The third major area of applicability is process control. Moisture sensors and noise analysis equipment developed at ORNL and PNL's development of high-temperature, high-pressure electrochemical probes could be of benefit. Nondestructive evaluation research and facilities of both AFWAL and PNL could lead to improved safety, product quality and more efficient quality control. Finally, AFWAL's integrated computer-aided manufacturing program would seem to be directly applicable to the textile industry.

INDUSTRY RESPONSE

In general, the response of industry to federal materials R&D confirmed the value of technology transfer activities and of the federal laboratories as a major national resource. The fundamental nature and early stage of much of the materials research seemed to preclude a significant, direct application to specific industrial processes in many cases. Still, individual R&D efforts were mentioned as being useful and familiarization with research programs and capabilities was certainly of value to most of the respondents. Organization of federal technologies by major process elements was mentioned specifically as being useful by some industry representatives.

CONTENTS

EXECUTIVE SUMMARY	i
1.0 INTRODUCTION	1.1
2.0 METHODOLOGY	2.1
3.0 APPLICABLE MATERIALS R&D BY MAJOR TAXONOMY ELEMENTS FOR SIX INDUSTRIES	3.1
4.0 MATERIALS RESEARCH AND DEVELOPMENT AT SELECTED FEDERAL LABORATORIES	4.1
4.1 AIR FORCE WRIGHT AERONAUTICAL LABORATORIES MATERIAL LABORATORY (AFWAL ML)	4.2
• Aluminum Casting/Powder Metallurgy	4.2
• Super Plastic Forming of Titanium	4.2
• Enhanced Productivity of Die Forging Systems	4.3
• Nondestructive Evaluation (NDE)	4.4
• Materials Life Prediction	4.6
• Integrated Computer-Aided Manufacturing (ICAM)	4.7
• Coatings	4.8
4.2 BATTELLE PACIFIC NORTHWEST LABORATORIES (PNL)	4.10
• Statistically Designed Optimization of Glass Mixture	4.10
• High Electronically Conducting Refractory Oxides	4.12
• High-Temperature Corrosion and Electromechanical Interactions in Ceramics	4.14
• Sputter Deposition Coating	4.16
• Improved Welding Technology	4.17
• Surface Science	4.19
• Stress Corrosion Research	4.24
• High-Temperature, High-Pressure Electrochemical Probes	4.25
• Nondestructive Evaluation (NDE)	4.28
• Full-Scale Pipe Test Facility	4.30
• High-Pressure/High-Temperature Autoclaves and Pipe Test Facilities	4.31
• Cable Tester	4.33

4.3 NATIONAL AERONAUTICS AND SPACE ADMINISTRATION MARSHALL SPACE FLIGHT CENTER (NASA MARSHALL)	4.34
● Variable Polarity Plasma Arc Welding	4.34
● Computer Modeling/Control of Welding	4.34
● Bearing Tests Data Base	4.35
● High-Speed Machining	4.36
● Stress Corrosion Testing Program	4.37
● Low Gravity Microsegregation Behavior	4.38
● Turbine Blade Coating Process	4.39
● Preparation of Silicon Carbide-Silicon Nitride Fibers	4.40
● Adhesive Bonding	4.41
● Development of Urethane Coating and Potting Material	4.42
● Firefighting Module Development	4.43
4.4 OAK RIDGE NATIONAL LABORATORY (ORNL)	4.44
● Lubricants for Warm Forming of Metals	4.44
● Friction and Wear of Ceramics at Elevated Temperatures	4.44
● Computer-Accessible System for Retrieval of Tribological Design Data	4.46
● Lubricating Qualities of the Constituents of Base Stock Oils	4.47
● Neutral Solvents	4.47
● Separations Chemistry	4.49
● Industrial Insulation, Refractories, and Recuperation	4.51
● Coatings for Corrosion/Erosion Resistance	4.52
● Amorphous Metals	4.53
● Long Range Ordered (LRO) and Ordered Intermetallic Alloys for High Temperature Structural Applications	4.54
● Structural Ceramics	4.55
● Sensors	4.57
4.5 BROOKHAVEN NATIONAL LABORATORY (BNL)	4.60
● Corrosion Research Capabilities	4.60
● Kinetics and Mechanisms of Alternative Fuels Combustion	4.61

• Calcium Silicate Cement Sorbent for H ₂ S Removal and Improved Coal Gasification Processes	4.63
• Research and Implementation of Concrete-Polymer Overlays and Patching Material	4.64
• Water-Compatible Polymer-Concrete Materials	4.66
• Geothermal Materials Development: Geothermal Well Cements	4.67
4.6 IDAHD NATIONAL ENGINEERING LABORATORY (INEL)	4.70
• The Determination and Identification of Microbial Production of Inducible Metallothionein-Protein	4.70
• Joining of Silicon Nitride Based Ceramics	4.71
• The Effect of Coal Gasification Atmospheres on Biaxial Creep of Alloys	4.71
• Mechanical Properties Design Data - 718 Stainless Steel	4.72
4.7 JET PROPULSION LABORATORY (JPL)	4.73
• Power Generation Turbine for Two-Phase (gas/liquid) Fluids in Waste Heat Streams	4.73
• Chemical Processes - Biocatalysis, Catalyst Modeling and Separation	4.75
• Biological Enhancement of Butanol Production Processes	4.78
5.0 RESPONSE OF INDUSTRY TO FEDERAL MATERIALS R&D	5.1
APPENDIX A - INDUSTRY TAXONOMIES	A.1

1.0 INTRODUCTION

Nearly 200 federal laboratories conduct research and development (R&D) in many areas including materials and process steps. This research and the related federal laboratory capabilities are of critical value to the private industrial sector when coupled with identified opportunities for improving energy efficiency and overall productivity of industrial processes. Yet, because the research can be in an unrelated area, and due to the time and resources required to identify and analyze such R&D, it can remain relatively unknown to many in private industry.

A recently completed test case^(a) in which work at six federal laboratories was surveyed for applicability to the pulp and paper industry showed that there was, in fact, value in the transfer of federally developed work to private industry. The test case showed that a significant amount of work underway at the federal labs (much of which the pulp and paper industry was unaware) has relevance to either the industry as a whole or to individual companies. Both the effort itself and the information presented were well received by the industry.

The purpose of the effort reported here is to transfer existing, but relatively unknown, advanced materials R&D at selected federal laboratories to the private sector. In the test case, a high level of industry response and interest was found for materials-related technologies. A decision was made for the present project to focus the effort on materials-related research and development while broadening the area of target industrial applications to include more of the energy-intensive manufacturing sector. More specifically, the latest results of R&D at seven federal laboratories potentially applicable to six energy-intensive manufacturing industries were identified, evaluated, cataloged, and distributed to industry representatives. The laboratories surveyed included: Air Force Wright Aeronautical Laboratories (AFWAL), Battelle Pacific Northwest Laboratories (PNL), National Aeronautics and Space Administration

(a) "Survey and Analysis of Federally Developed Technology," PNL-4499, February 1983.

Marshall Space Flight Center (NASA Marshall), Oak Ridge National Laboratory (ORNL), Brookhaven National Laboratory (BNL), Idaho National Engineering Laboratory (INEL), and Jet Propulsion Laboratory (JPL). The manufacturing industries included are: aluminum, cement, pulp and paper, petroleum, steel and textiles.

Topics discussed in subsequent sections of the report are as follows: Section 2.0 of the report outlines the methodology employed in identifying and evaluating federal laboratory capabilities and materials R&D potentially applicable to the six manufacturing industries. In Section 3.0, lists of all federal work applicable to the specific industries according to the major process elements are presented. In Section 4.0 profiles of all of the federal R&D efforts, arranged according to the laboratory of origin, are presented. Finally, Section 5.0 examines the response of industry representatives to the federal R&D with respect to the perceived value of the information presented and to the receptivity to the direct transfer of such results to industry.

2.0 METHODOLOGY

As a first step in this project, taxonomies of the six energy-intensive manufacturing industries included in this effort were prepared. The six industries are:

- aluminum,
- cement,
- paper and allied products,
- petroleum,
- steel, and
- textiles.

The taxonomies (see Appendix A) describe the major processes and activities from raw material acquisition to completion of the manufactured goods. The taxonomies provide a means of organizing and cross-referencing opportunities for improved process energy efficiency and productivity and applicable federal R&D. Moreover, the taxonomies allow industry to readily identify federally-developed material technologies applicable to particular sectors of the industry.

While the taxonomy was being developed, the major program areas, unique technical expertise, and existing technology transfer activities at the seven federal laboratories surveyed were identified. In this review process, appropriate documents were obtained from each laboratory using their respective Technology Utilization Officers as points of contact. Their officers have responsibility for federal laboratory compliance with the Stevenson-Sydler Technology Innovative Act of 1980 (PNL-96-480).

Using the taxonomy as a guide, the project team convened brainstorming sessions to identify problems in the industry and possible laboratory programs that may bear on those problems. These sessions emphasized "open mindedness," i.e., no idea was considered unacceptable. The document resulting from these sessions consisted of industry taxonomies on which was overlaid the project team's perception of work underway in laboratories that could impact opportunities within each element. This document was then sent to each laboratory to

provide an advanced insight into the scope and depth of the investigation prior to the project team's visit or alternative form of inquiry.

Four of the seven selected federal laboratories were then visited by the project team, and the remaining three laboratories were queried by telephone and written communications. The labs visited were:

- Air Force Wright Aeronautical Laboratories Material Laboratory (AFWAL)
- Battelle Pacific Northwest Laboratory (PNL)
- NASA Marshall Space Flight Center (NASA Marshall)
- Oak Ridge National Laboratory (ORNL).

Laboratories queried but not visited were:

- Brookhaven National Laboratory (BNL)
- Idaho National Engineering Laboratory (INEL)
- Jet Propulsion Laboratory (JPL)

The laboratory visits typically involved an initial presentation to a small group of senior technical managers selected by the Technology Utilization Officer. Principal investigators working in technology areas related to elements of the taxonomy were identified in the initial meeting. These principal investigators were then each interviewed, and the resulting notes and technical documents became the information base for the project.

The three laboratories queried but not visited were approached in an analogous manner. Like the visited labs, a detailed letter was sent to each laboratory's Technology Utilization Officer (TUO) enclosing copies of the taxonomy document and indicating early perceptions of the laboratory's material R&D activities of most interest. For the queried labs this inquiry also asked for referrals to the appropriate materials research management personnel, or, at the TUO's option, the names and telephone numbers of appropriate principal investigators to be interviewed by telephone to ascertain the applicability of their work and to request technical information on the most promising technologies. Ultimately, four to six principal investigators at each laboratory were

contacted by written and telephone communication to obtain information on applicable R&D efforts.

A very liberal approach was taken to determine the applicability of federal R&D efforts to particular industrial process elements. In only a few cases was the work uncovered aimed directly at improving a particular industrial process. More often the work was directed at an unrelated area, and was evaluated for potential application to other areas assuming successful completion of the work effort. Typically, the general expectations from the work effort (normally a material with certain improved characteristics) was coupled with identified industrial (often generalized) needs. Thus, the application of a federal work effort to an industrial process may not always be direct or immediate.

Follow-up activities included the cataloging of all information gathered, additional communication with the principal investigators, and the development of formatted profiles for each technology. These profiles list the technology name; the principal investigator along with his telephone number, title, and organizational code; applicable taxonomy elements; a narrative description of the R&D effort; and reference material.

The next step was to review the technology findings with industry representatives. All R&D efforts potentially applicable to each particular industry were compiled, arranged according to taxonomy elements, and distributed to two or three industry representatives in notebook form, along with a letter explaining the project's intent and requesting their review comments.

Finally, the industry responses received were compiled to obtain a summary of industry reaction, and this final report was prepared on the effort.

3.0 APPLICABLE MATERIALS R&D BY MAJOR TAXONOMY ELEMENT FOR SIX INDUSTRIES

This section provides a list of federally-sponsored materials R&D that is potentially applicable to the major taxonomic (process) elements of six manufacturing industries. These industries are:

- Aluminum (Table 3.1)
- Cement (Table 3.2)
- Pulp and Paper (Table 3.3)
- Petroleum (Table 3.4)
- Steel (Table 3.5), and
- Textiles (Table 3.6)

Each industry list gives the R&D program title, categorized by taxonomic element, and shows the page number in Section 4.0 on which a summary description of the R&D program can be found. Appendix A provides the detailed taxonomies for each industry.

TABLE 3.1 Materials R&D Applicable to the Aluminum Industry

	<u>Page</u>
1.0 MINING AND TRANSPORTATION	
● Surface Science	4.19
● Turbine Blade Coating Process	4.39
● Preparation of Silicon Carbide-Silicon Nitride Fibers	4.40
● Computer-Accessible System for Retrieval of Tribological Design Data	4.46
● Lubricating Qualities of the Constituents of Base Stock Oils	4.47
● Coatings for Corrosion/Erosion Resistance	4.52
2.0 BAUXITE PROCESSING	
● Sputter Deposition Coating	4.16
● Bearing Tests Data Base	4.35
● Computer-Accessible System for Retrieval of Tribological Design Data	4.46
● Coatings for Corrosion/Erosion Resistance	4.52
● Amorphous Metals	4.53
● Sensors	4.57
3.0 ALUMINA REFINING	
● Coatings for Corrosion/Erosion Resistance	4.52
● Sensors	4.57
4.0 SMELTING	
● High-Temperature Corrosion and Electrochemical Interactions in Ceramics	4.14
● Adhesive Bonding	4.41
● Industrial Insulation, Refractories, and Recuperation	4.51
● Structural Ceramics	4.55
● The Effect of Coal Gasification Atmospheres on Biaxial Creep of Alloys	4.71

TABLE 3.1 (contd)

5.0 ALLOYING

● High-Temperature Corrosion and Electrochemical Interactions in Ceramics	4.14
● Sputter Desposition Coating	4.16
● Surface Science	4.19
● Low Gravity Microsegregation Behavior	4.38
● Adhesive Bonding	4.41
● Industrial Insulation, Refractories and Recuperation	4.51
● Long Range Ordered (LRO) and Ordered Inter-metallic Alloys for High Temperature Structural Applications	4.54
● Corrosion Research Capabilities	4.60
● Joining of Silicon Nitride Based Ceramics	4.71
● The Effect of Coal Gasification Atmospheres on Biaxial Creep of Alloys	4.71
● Mechanical Properties Design Data - 718 Stainless Steel	4.72

6.0 FABRICATION AND MILLING

● Aluminum Casting/Powder Metallurgy	4.2
● Superplastic Forming of Titanium	4.2
● Enhanced Productivity of Die Forging Systems	4.3
● High-Temperature Corrosion and Electrochemical Interactions in Ceramics	4.14
● Improved Welding Technology	
● Variable Polarity Plasma Arc Welding	4.34
● Computer Modeling/Control of Welding	4.34
● High-Speed Machining	4.36
● Preparation of Silicon Carbide-Silicon Nitride Fibers	4.40
● Lubricants for Warm Forming of Metals	4.44
● Computer Accessible System for Retrieval of Tribological Design Data	4.46
● Coatings for Corrosion/Erosion Resistance	4.52

TABLE 3.1 (contd)

7.0 PROCESS CONTROL

- Nondestructive Evaluation (NDE) 4.4
- Integrated Computer-Aided Manufacturing (ICAM) 4.7
- High Electronically Conducting Refractory Oxides 4.12
- High Temperature, High Pressure Electrochemical Probes 4.25

8.0 HEALTH, SAFETY, AND POLLUTION CONTROL

- Nondestructive Evaluation (NDE) 4.4
- Materials Life Prediction 4.6
- Stress Corrosion Research 4.24
- Nondestructive Evaluation (NDE) 4.28
- Full-Scale Pipe Test Facility 4.30
- High Pressure/High Temperature Autoclaves
and Pipe Test Facilities 4.31
- Cable Tester 4.33
- Stress Corrosion Testing Program 4.37
- Separations Chemistry 4.49
- Kinetics and Mechanisms of Alternative Fuels Combustion 4.61
- The Determination and Identification of Microbial
Production of Inducible Metallothionein-Protein 4.70

9.0 SCRAP

- No directly applicable technologies

TABLE 3.2 Materials R&D Applicable to the Cement Industry

	<u>Page</u>
1.0 QUARRYING AND TRANSPORTATION	
● Sputter Deposition Coating	4.16
● Turbine Blade Coating Process	4.39
● Preparation of Silicon Carbide-Silicon Nitride Fibers	4.40
● Computer-Accessible System for Retrieval of Tribological Design Data	4.46
● Lubricating Qualities of the Constituents of Base Stock Oils	4.47
● Coatings for Corrosion/Erosion Resistance	4.52
● Amorphous Metals	4.53
● Structural Ceramics	4.55
2.0 CRUSHING AND GRINDING	
● Sputter Deposition Coating	4.16
● Bearing Tests Data Base	4.35
● Friction and Wear of Ceramics at Elevated Temperature	4.44
● Computer-Accessible System for Retrieval of Tribological Design Data	4.46
● Coatings for Corrosion/Erosion Resistance	4.52
● Amorphous Metals	4.53
● Structural Ceramics	4.55
● Sensors	4.57
● The Effect of Coal Gasification Atmospheres on Biaxial Creep of Alloys	4.71
3.0 PYROPROCESSING	
● High Electrically Conducting Refractory Oxides	4.12
● High Temperature Corrosion and Electrochemical Interactions in Ceramics	4.14
● Adhesive Bonding	4.41
● Industrial Insulation, Refractories and Recuperation	4.51
● Sensors	4.55

TABLE 3.2 (contd)

4.0 CLINKER COOLING

- Joining of Silicon Nitride Based Ceramics 4.71

5.0 FINAL GRINDING

- Sputter Deposition Coating 4.16
- Bearing Tests Data Base 4.35
- Friction and Wear of Ceramics at Elevated Temperature . . 4.44
- Computer-Accessible System for Retrieval of
Tribological Design Data 4.46
- Coatings for Corrosion/Erosion Resistance 4.52
- Amorphous Metals 4.53
- Structural Ceramics 4.55
- Sensors 4.57

6.0 PROCESS CONTROL SYSTEMS

- Nondestructive Evaluation (NDE) 4.4
- Integrated Computer-Aided Manufacturing (ICAM) 4.7
- Statistically Designed Optimization of a
Glass Composition 4.10
- High Electronically Conducting Refractory Oxides 4.12
- High Temperature, High Pressure Electrochemical Probes . . 4.25
- Calcium Silicate Sorbent for H₂S Removal and
Improved Coal Gasification Processes 4.63
- Research and Implementation of Concrete-Polymer
Overlays and Patching Material 4.64
- Water Compatible Polymer-Concrete Materials 4.66
- Geothermal Materials Development:
Geothermal Well Cements 4.67

7.0 HEALTH, SAFETY, AND POLLUTION CONTROL

- Nondestructive Evaluation (NDE) 4.4
- Materials Life Prediction 4.6

TABLE 3.2 (contd)

● Coatings	4.8
● Stress Corrosion Research	4.24
● Nondestructive Evaluation (NDE)	4.28
● Full-Scale Pipe Test Facility	4.30
● High Pressure/High Temperature Autoclaves and Pipe Test Facilities	4.31
● Cable Tester	4.33
● Stress Corrosion Testing Program	4.37
● Kinetics and Mechanisms of Alternative Fuels Combustion	4.61

TABLE 3.3 Materials R&D Applicable to the Pulp and Paper Industry

	<u>Page</u>
1.0 TREE SEEDLING PRODUCTION AND GENETIC DEVELOPMENT	
No directly applicable technologies	
2.0 FOREST LAND PREPARATION, STOCKING AND YIELD MANAGEMENT	
● Firefighting Module Development	4.43
3.0 TIMBER HARVESTING, TRANSPORTATION AND STORAGE	
● Sputter Deposition Coating	4.16
● Bearing Tests Data Base	4.35
● Turbine Blade Coating Process	4.39
● Computer-Accessible System for Retrieval of Tribological Design Data	4.46
● Coatings for Corrosion/Erosion Resistance	4.52
● Amorphous Metals	4.53
● Structural Ceramics	4.55
4.0 DEBARKING AND CHIPPING	
● Sputter Deposition Coating	4.16
● Bearing Tests Data Base	4.35
● Computer-Accessible System for Retrieval of Tribological Design Data	4.46
● Coatings for Corrosion/Erosion Resistance	4.52
● Amorphous Metals	4.53
● Structural Ceramics	4.55
● Sensors	4.57
5.0 PULPING AND BLEACHING	
● Sputter Deposition Coating	4.16
● Surface Science	4.19
● Bearing Tests Data Base	4.35
● Adhesive Bonding	4.41

TABLE 3.3 (contd)

● Friction and Wear of Ceramics at Elevated Temperature	4.44
● Computer-Accessible System for Retrieval of Tribological Design Data	4.46
● Coatings for Corrosion/Erosion Resistance	4.52
● Amorphous Metals	4.53
● Structural Ceramics	4.55
● Sensors	4.57
● Power Generation Turbine for Two-Phase (Gas/Liquid) Fluids in Waste Heat Streams	4.73
● Chemical Processes-Biocatalysis, Catalyst Modeling and Separation	4.75
6.0 PAPER AND PAPERBOARD PRODUCTION	
● Sputter Deposition Coating	4.16
● Surface Science	4.19
● Adhesive Bonding	4.41
● Amorphous Metals	4.53
● The Effect of Coal Gasification Atmospheres on Biaxial Creep of Alloys	4.71
7.0 COATING AND CONVERTING	
● Computer-Accessible System for Retrieval of Tribological Design Data	4.46
8.0 OTHER CELLULOSIC	
● Chemical Process-Biocatalysis, Catalyst Modeling and Separation	4.75
9.0 WASTE PAPER	
No directly applicable technologies.	
10.0 PROCESS CONTROL	
● Nondestructive Evaluation (NDE)	4.4

TABLE 3.3 (contd)

● Integrated Computer-Aided Manufacturing (ICAM)	4.7
● High Electronically Conducting Refractory Oxides	4.12
● High Temperature, High Pressure Electrochemical Probes	4.25
● Development of Urethane Coating and Potting Material	4.42
● Sensors	4.57

11.0 POWER AND CHEMICAL RECOVERY

● Coatings	4.8
● Sputter Deposition Coating	4.16
● Surface Science	4.19
● Friction and Wear of Ceramics at Elevated Temperatures	4.44
● Neutral Solvents	4.47
● Separations Chemistry	4.49
● Amorphous Metals	4.53
● Long Range Ordered and Ordered Intermetallic Alloys for High Temperature Structural Applications	4.54
● Structural Ceramics	4.55
● Sensors	4.57
● Corrosion Research Capabilities	4.60
● Kinetics and Mechanisms of Alternative Fuels Combustion	4.61
● Mechanical Properties Design Data - 718 Stainless Steel	4.72
● Power Generation Turbine for Two-Phase (Gas/Liquid) Fluids in Waste Heat Streams	4.73
● Biological Enhancement of Butanol Production Processes	4.78

12.0 HEALTH, SAFETY, AND POLLUTION CONTROL

● Nondestructive Evaluation	4.4
● Materials Life Prediction	4.6
● Stress Corrosion Research	4.24

TABLE 3.3 (contd)

● Nondestructive Evaluation	4.28
● Full-Scale Pipe Test Facility	4.30
● High Pressure/High Temperature Autoclaves and Pipe Test Facilities	4.31
● Stress Corrosion Testing Program	4.37
● Separations Chemistry	4.49
● Kinetics and Mechanisms of Alternative Fuels Combustion	4.61
● Biological Enhancement of Butanol Production Processes	4.78
● Chemical Processes-Biocatalysis, Catalyst Modeling and Separation	4.75

TABLE 3.4 Materials R&D Applicable to the Petroleum Industry

1.0 EXPLORING

- Surface Science 4.19

2.0 DRILLING AND RECOVERY

- Sputter Deposition Coating 4.16
- Bearing Tests Data Base 4.35
- Friction and Wear of Ceramics at Elevated Temperature . 4.44
- Computer-Accessible System for Retrieval
of Tribological Design Data 4.46
- Coatings for Corrosion/Erosion Resistance 4.52
- Amorphous Metals 4.53
- Structural Ceramics 4.55
- Sensors 4.57
- Geothermal Materials Department:
Geothermal Well Cements 4.67
- Power Generation Turbine for Two-Phase (Gas/Liquid)
Fluids in Waste Heat Streams 4.73
- Biological Enhancement of Butanol Production Processes . 4.78

3.0 TRANSPORTING

- Improved Welding Technology 4.17
- Variable Polarity Plasma Arc Welding 4.34
- Computer Modeling/Control of Welding 4.34
- Turbine Blade Coating Process 4.39

4.0 WASHING

- Surface Science 4.19
- Friction and Wear of Ceramics at Elevated Temperature . 4.44
- Corrosion Research Capabilities 4.60
- The Determination and Identification of
Microbial Production of Inducible
Metallothionein-Protein 4.70

TABLE 3.4 (contd)

● The Effect of Coal Gasification Atmospheres on Biaxial Creep of Alloys	4.71
● Chemical Process-Biocatalysis, Catalyst Modeling and Separation	4.75
5.0 SEPARATION	
● Sputter Deposition Coating	4.16
● Surface Science	4.19
● Adhesive Bonding	4.41
● Friction and Wear of Ceramics at Elevated Temperature	4.44
● Amorphous Metals	4.53
● Industrial Insulation, Refractories and Recuperation	4.51
● Long Range Ordered (LRO) and Ordered Inter-metallic Alloys for High Temperature Structural Applications	4.54
● Structural Ceramics	4.55
● Corrosion Research Capabilities	4.60
● The Effect of Coal Gasification Atmospheres on Biaxial Creep of Alloys	4.71
● Mechanical Properties Design Data - 718 Stainless Steel	4.72
● Chemical Processes-Biocatalysis, Catalyst Modeling and Separation	4.75
6.0 CONVERSION	
● Sputter Deposition Coating	4.16
● Surface Science	4.19
● Adhesive Bonding	4.41
● Amorphous Metals	4.53
● Friction and Wear of Ceramics at Elevated Temperature	4.44
● Industrial Insulation, Refractories and Recuperation	4.51
● Long Range Ordered and Ordered Inter-Metallic Alloys for High Temperature Structural Applications	4.54

TABLE 3.4 (contd)

● Structural Ceramics	4.55
● Corrosion Research Capabilities	4.60
● Joining of Silicon Nitride Based Ceramics	4.71
● The Effect of Coal Gasification Atmospheres on Biaxial Creep of Alloys	4.71
● Mechanical Properties Design Data - 718 Stainless Steel	4.72
● Power Generation Turbine for Two-Phase (Gas/Liquid) Fluids in Waste Heat Streams	4.73
● Chemical Processes-Biocatalysis, Catalyst Modeling and Separation	4.75
● Biological Enhancement at Butanol Production Processes	4.78

7.0 CHEMICAL TREATMENT

● Statistically Designed Optimization of a Glass Composition	4.10
● Surface Science	4.19
● Friction and Wear of Ceramics at Elevated Temperature	4.44
● Lubricating Qualities of the Constituents of Base Stock Oils	4.47
● Neutral Solvents	4.47
● The Effect of Coal Gasification Atmospheres on Biaxial Creep of Alloys	4.71
● Mechanical Properties Design Data - 718 Stainless Steel	4.72
● Chemical Processes-Biocatalysis, Catalyst Modeling and Separation	4.75

8.0 PROCESS CONTROL

● Nondestructive Evaluation (NDE)	4.4
● Integrated Computer-Aided Manufacturing (ICAM)	4.7
● High Electronically Conducting Refractory Oxides	4.12
● High Temperature, High Pressure Electrochemical Probes	4.25
● Development of Urethane Coating and Potting Material	4.42

TABLE 3.4 (contd)

9.0 HEALTH, SAFETY, AND POLLUTION CONTROL

● Nondestructive Evaluation	4.4
● Materials Life Prediction	4.6
● Coatings	4.8
● Surface Science	4.19
● Stress Corrosion Research	4.24
● Nondestructive Evaluation	4.28
● Full-Scale Pipe Test Facility	4.30
● High Pressure/High Temperature Autoclaves and Pipe Test Facilities	4.31
● Cable Tester	4.33
● Stress Corrosion Testing Program	4.37
● Firefighting Module Development	4.43
● Separations Chemistry	4.49
● Kinetics and Mechanisms of Alternative Fuels Combustion	4.61
● Calcium Silicate Cement Sorbent for H ₂ S Removal and Improved Coal Gasification Processes	4.63
● Mechanical Properties Design Data - 718 Stainless Steel	4.72
● The Determination and Identification of Microbial Production of Inducible Metallothionein-Protein	4.70
● Chemical Processes-Biocatalysis, Catalyst Modeling and Separation	4.75

10.0 USED OIL

● Surface Science	4.19
● Corrosion Research Capability	4.60

TABLE 3.5 Materials R&D Applicable to the Steel Industry

	<u>Page</u>
1.0 AGGLOMERATION	
● Industrial Insulation, Refractories, and Recuperation	4.51
2.0 SMELTING	
● High Temperature Corrosion and Electrochemical Interactions in Ceramics	4.14
● Surface Science	4.19
● Industrial Insulation, Refractories, and Recuperation	4.51
● The Effect of Coal Gasification Atmospheres on Biaxial Creep of Alloys	4.71
● Mechanical Properties Design Data - 718 Stainless Steel	4.72
● Chemical Processes-Biocatalysis, Catalyst Modeling and Separation	4.75
3.0 STEELMAKING	
● High Temperature Corrosion and Electrochemical Interactions in Ceramics	4.14
● Surface Science	4.19
● Adhesive Bonding	4.41
● Industrial Insulation, Refractories, and Recuperation	4.51
● Joining of Silicon-Nitride Based Ceramics	4.71
● The Effect of Coal Gasification Atmospheres on Biaxial Creep of Alloys	4.71
● Mechanical Properties Design Data - 718 Stainless Steel	4.72
4.0 CASTING	
● High Temperature Corrosion and Electrochemical Interactions in Ceramics	4.14

TABLE 3.5 (contd)

● Surface Science	4.19
● Low Gravity Microsegregation Behavior.	4.38
● Preparation of Silicon Carbide-Silicon Nitride Fibers	4.40
● Adhesive Bonding	4.41
● Computer-Accessible System for Retrieval of Tribological Design Data	4.46
● Long Range Ordered and Ordered Intermetallic Alloys for High Temperature Structural Applications	4.54
● Industrial Insulation, Refractories, and Recuperation	4.51
● Structural Ceramics	4.55
● Chemical Processes-Biocatalysis, Catalyst Modeling and Separation	4.75

5.0 FABRICATION

● Superplastic Forming of Titanium	4.2
● Enhanced Productivity of Die Forging Systems	4.3
● High Temperature Corrosion and Electrochemical Interactions in Ceramics	4.14
● Sputter Deposition Coating	4.16
● Surface Science	4.19
● Improved Welding Technology	4.17
● Variable Polarity Plasma Arc Welding	4.34
● Computer Modeling/Control of Welding	4.34
● Bearing Tests Data Base	4.35
● High Speed Machining	4.36
● Preparation of Silicon Carbide-Silicon Nitride Fibers	4.40
● Adhesive Bonding	4.41
● Lubricants for Warm Forming of Metals	4.44
● Computer-Accessible System for Retrieval of Tribological Design Data	4.46

TABLE 3.5 (contd)

● Industrial Insulation, Refractories and Recuperation	4.51
● Coatings for Corrosion/Erosion Resistance	4.52
● Amorphous Metals	4.53
● Long Range Ordered and Ordered Intermetallic Alloys for High Temperature Structural Applications	4.54
● Structural Ceramics	4.55
● Corrosion Research Capabilities	4.60
● Joining of Silicon Nitride Based Ceramics	4.71

6.0 PROCESS CONTROLS

● Nondestructive Evaluation	4.4
● Integrated Computer-Aided Manufacturing	4.7
● High Electronically Conducting Refractory Oxides	4.12
● High Temperature, High Pressure Electro-chemical Probes	4.25
● Development of Urethane Coating and Potting Material	4.42
● Sensors	4.57

7.0 HEALTH, SAFETY, AND POLLUTION CONTROL

● Nondestructive Evaluation	4.4
● Materials Life Prediction	4.6
● Stress Corrosion Research	4.24
● Nondestructive Evaluation	4.28
● Full-Scale Pipe Test Facility	4.30
● High Pressure/High Temperature Autoclaves and Pipe Test Facilities	4.31
● Cable Tester	4.33
● Stress Corrosion Testing Program	4.37
● Separations Chemistry	4.49
● Kinetics and Mechanisms of Alternative Fuels Combustion	4.61
● The Determination and Identification of Microbial Production of Inducible Metallothionein-Protein	4.70

8.0 COKEMAKING

- Industrial Insulation, Refractories and Recuperation . 4.51

9.0 SCRAP

No directly applicable technologies

TABLE 3.6 Materials R&D Applicable to the Textile Industry

	<u>Page</u>
1.0 FIBER	
● Coatings for Corrosion/Erosion Resistance	4.52
● Amorphous Metals	4.53
2.0 YARN MAKING	
● Sputter Deposition Coating	4.16
● Bearing Tests Data Base	4.35
● Turbine Blade Coating Process	4.39
● Computer-Accessible System for Retrieval of Tribological Design Data	4.46
● Coatings for Corrosion Erosion/Resistance	4.52
● Amorphous Metals	4.53
● Sensors	4.57
3.0 FABRIC CONSTRUCTION	
● Sputter Deposition Coating	4.16
● Bearing Tests Data Base	4.35
● Turbine Blade Coating Process	4.39
● Computer-Accessible System for Retrieval of Tribological Design Data	4.46
● Coatings for Corrosion Erosion/Resistance	4.52
● Amorphous Metals	4.53
● Sensors	4.57
4.0 FABRIC FINISHING	
● Sputter Deposition Coating	4.16
● Turbine Blade Coating Process	4.39
● Coatings for Corrosion Erosion/Resistance	4.52
● Amorphous Metals	4.53
● Sensors	4.57

TABLE 3.6 (contd)

5.0 PROCESS CONTROL

● Nondestructive Evaluation	4.4
● Integrated Computer-Aided Manufacturing	4.7
● High Electronically Conducting Refractory Oxides	4.12
● High Temperature, High Pressure Electrochemical Probes	4.25

6.0 HEALTH, SAFETY, AND POLLUTION CONTROL

● Nondestructive Evaluation	4.4
● Materials Life Prediction	4.6
● Stress Corrosion Research	4.25
● Nondestructive Evaluation	4.28
● Full-Scale Pipe Test Facility	4.30
● High Pressure/High Temperature Autoclaves and Pipe Test Facilities	4.31
● Stress Corrosion Testing Program	4.37
● Separations Chemistry	4.49
● Kinetics and Mechanisms of Alternative Fuels Combustion	4.61
● The Determination and Identification of Microbial Production of Inducible Metallothionein-Protein	4.70

4.0 MATERIALS RESEARCH AND DEVELOPMENT AT SELECTED FEDERAL LABORATORIES

Presented in this section are profiles of federal R&D efforts identified during the course of this project that are thought to be potentially applicable to improving process energy efficiency and productivity in six energy-intensive industries. Profiles include:

- technology (R&D effort) name;
- a list of potentially applicable industries and process elements;
- laboratory of origin;
- the name, title and telephone number of the principal contact(s);
- a summary description of the R&D effort; and
- reference materials.

The profiles are arranged according to the laboratory of origin and include profiles for four visited laboratories and three laboratories queried by telephone and written communication but not visited. The laboratories are:

Visited Laboratories

- Air Force Wright Aeronautical Laboratories Material Laboratory (AFWAL)
- Battelle Pacific Northwest Laboratories (PNL)
- National Aeronautical and Space Administration Marshall Space Flight Center (NASA Marshall)
- Oak Ridge National Laboratory (ORNL)

Queried Laboratories

- Brookhaven National Laboratory (BNL)
- Idaho National Engineering Laboratory (INEL)
- Jet Propulsion Laboratory (JPL)

The federal materials R&D identified in this section are by no means all of the work conducted by the laboratory in question or even all of the materials related work. Nor does it necessarily represent the most up-to-date account of work being performed although it was intended to include only current work efforts.

4.1 AIR FORCE WRIGHT AERONAUTICAL LABORATORIES MATERIAL LABORATORY (AFWAL)

TECHNOLOGY: Aluminum Casting/Powder Metallurgy

Applicable Industry; Process Element(s):

Aluminum; 6.1 Fabrication

Laboratory: AFWAL

Contact: Edward Schopler
Metals Fabrication Area
(513) 255-5037

An objective of this research is a 3,000 lb flawless, controlled grain size, out-gassed casting that can be rolled into a continuous skin (sheet stock) for covering airframes. Rapid solidification rate casting is a major thrust. It is intended to use the castings as primary structure; a major accomplishment is a single piece airframe bulkhead measuring approximately 7 ft by 4 ft and weighing 185 lbs. Trim losses are reduced using the casting process, and less primary metal is required as a result. Also, requirements for fasteners are reduced significantly and therefore the number of holes (crack sites) in primary structure is greatly reduced; cost and useful life are very favorably enhanced.

TECHNOLOGY: Superplastic Forming of Titanium

Applicable Industry; Process Element(s):

Aluminum: 6.1 Fabrication^(a)
Steel: 5.0 Fabrication

Laboratory: AFWAL

Contact: J.R. Williamson
Metals Fabrication Area
(513) 255-5037

An exciting capability demonstrated at AFWAL Material Lab is the superplastic forming of titanium, particularly complex unitized components, honeycomb and heat exchanger like. Two skins are diffusion bonded to a complex sandwich piece and the piece is then expanded by argon pressure in a die to

(a) All subsequent applicable industry listings shown with a superscript (a) will indicate the most applicable industry.

form a desired complex shape. The temperature of the piece and the rate of pressure application are closely controlled during the process. Current research is on maintaining piece temperature without requiring the die to be at temperature. Other research is focused on acquiring a similar capability with other materials such as iron and aluminum-based materials. A major difficulty with aluminum is the desire not to diffusion bond.

Reference:

1. "Superplastic Forming of Structural Alloys: Conference Proceedings," The Metallurgical Society of America, Warrendale, PA, June 21-24, 1982.

TECHNOLOGY: Enhanced Productivity of Die Forging Systems

Applicable Industry; Process Element(s):

Aluminum:	6.1.1.1	Die Casting ^(a)
	6.2.2	Extrusion Mill Process
Steel:	5.2	Forging
	5.3	Extrusion

Laboratory: AFWAL

Contact: Hal L. Gege
AFWAL/MLLM
(513) 255-7371

Hal Gege described a methodology investigated at AFWAL ML that could rapidly revolutionize the manufacture of net shapes by die forging or extrusion. The methodology proceeds from the premises that: 1) material properties (starting, in-process, final) can be specified and temperature, pressure and energy input, and dissipation rates can be specified and controlled, and 2) an economic model in incremental cost can be applied to bound the utility of the process. The methodology integrates computer-aided design and computer-aided manufacturing. Where material properties as a function of the range of available forging environments are adequately known, a finite element program can be input and combined with advanced computer-aided engineering to yield a streamlined die design and a forging process that produces the desired product. The program can be validated on analog materials, e.g., lead substituted for aluminum/SiC whisker matrix to produce a wooden die analog of a steel die. It has been used successfully to produce the foregoing analog and end products.

A visiting scientist/engineer program and more formal programs with academic and industrial associations are available to transfer the new technology to industry.

Reference:

1. H.L. Gegel et al., "Computer-Aided Design of Extrusion and Forging Dies by Metal Flow Simulation," n.d. ^(b)

TECHNOLOGY: Nondestructive Evaluation (NDE)

Applicable Industry; Process Element(s):

Aluminum:	7.0	Process Control	^(a)
	8.0	Safety	
Cement:	6.0	Process Control	
	7.0	Safety	
Paper:	10.0	Process Control	
	12.0	Safety	
Petroleum:	8.0	Process Control	
	9.0	Safety	
Steel:	6.0	Process Control	
	7.0	Safety	
Textiles:	5.0	Process Control	
	6.0	Safety	

Laboratory: AFWAL ML

Contact: D.M. Forney
Chief, NDE Branch
(513) 255-3803

The nondestructive evaluation (NDE) branch at AFWAL Materials Laboratory conducts extensive research on all aspects of nondestructive evaluation. The current (April 1983) USAF NDE Exploratory Development and Manufacturing Technology R&D Program Plan identifies 40 specific program elements (directions) under six larger program thrusts. The larger thrusts are: NDE of engine components, composite NDE methods, field NDE reliability improvement, NDE of complex airframe structures, manufacturing process control NDE, and advanced NDE technology. Although the work is directed towards meeting Air Force needs, much of it could also benefit industry in the areas of safety, improved product quality and more efficient quality control, and improved manufacturing capability.

(b) All subsequent superscript (b) listings will indicate that the document is contained in the project file.

Several areas with more significant application to manufacturing industries are described below.

Corrosion Detection System Design

The purpose here is to develop and evaluate nondestructive inspection techniques applicable to the problem of detecting corrosion in its early stages in aluminum and steel multilayer joint aircraft structural configurations. Emphasis in this program will be on the detection of corrosion in underlying structural components, i.e., those sections of airframe structure that are normally inaccessible to visual inspection. Thus, a generic structure (or structures) containing corrosion or corrosion-like anomalies will be fabricated that represents as closely as possible, a number of airframe configurations in terms of the type of materials, number of material layers, the presence of sealant, and structural thickness variation. The generic structure(s) will be used to evaluate the capability of various NDE techniques that have the potential of ultimately being employed at the depot inspection level, and particular interest will be given to those techniques that have the potential of expeditiously inspecting large areas of airframe structure. If successful, this program will be followed by a Mantech program to produce an operational system.

Advanced Ultrasonic (U/S) Methods for Casting

U/S inversion algorithms are being tested for their applicability to multiple objects, to determine parameters such as porosity, as well as to test the degrading effect of rough interfaces on the U/S signal information.

Automated Parts Handling and Verification System

Manufacturing technology is being established to produce a prototype operational automated inspection system with high throughput rates to verify dimensional measurements of a range of airframe structural components during fabrication operations. The system prototype will be computer controlled and may, when completed, include such options as laser gaging, coordinate measuring, camera imaging, surface digitizer and a component handling and positioning subsystem. The system will also feature innovative parts identification methods,

improved inspection planning techniques, "self-teaching" inspection capabilities and automated record keeping and report generation functions. Prototype evaluation is scheduled to begin in 1983.

In-Process Control} NDE System Concepts

The purpose of this program will be to develop inspection and evaluation techniques applicable to the monitoring of material quality during the manufacturing process. The emphasis in the program will be on "in-process" inspection and evaluation of the material during manufacture as opposed to an "end-of-process" inspection of the manufactured product. Potential applications of interest to the Air Force include the lay-up and cure of structural composites, the forging process, and the fabrication of electronic materials.

Reference:

1. "The Current USAF NDE Exploratory Development and Manufacturing Technology R&D Plan (current to April 1983)"^(b)

TECHNOLOGY: Materials Life Prediction

Applicable Industry; Process Element(s):

Aluminum:	8.0	Safety ^(a)
Cement:	7.0	Safety
Paper:	12.0	Safety
Petroleum:	9.0	Safety
Steel:	7.0	Safety
Textiles:	6.0	Safety

Laboratory: AFWAL

Contact: Dr. T. Nicholas
Materials Life Prediction Area
(513) 255-2689

Maintaining an excessive inventory of spare parts is costly, and removal of components/equipment from service life after a specified cumulative number of hours in use is frequently wasteful. Therefore, a philosophy of component/equipment "retirement for cause" is being researched and implemented at AFWAL. The philosophy is based on the premise that remaining useful life can be predicted on the basis of periodic inspections and the analysis of detected wear and flaws. More specifically, the component tolerance for existing damage is assessed and use is permitted in accordance with a revised inspection frequency

until such time as flaws grow to the point where removal from service is required. Implementation of such a program on selected critical/costly components/equipment should be beneficial to numerous industrial processes.

Reference(s):

1. J.A. Harris et al., "Concept Definition: Retirement for Cause of F100 Rotor Components," AFWAL-TR-80-4118, prepared by Pratt & Whitney Aircraft Group, September 1980 (available from NTIS).
2. "Damage Tolerant Design for Cold-Section Turbine Engine Disks," AFWAL-TR-81-2045, prepared by United Technologies, Pratt & Whitney Aircraft, June 1981 (available from NTIS).
3. R.J. Hill, W.H. Reimann, and J.S. Ogg, "A Retirement for Cause Study of an Engine Turbine Disk," AFWAL-TR-81-2094, November 1981 (available from NTIS).

TECHNOLOGY: Integrated Computer-Aided Manufacturing (ICAM)

Applicable Industry; Process Element(s):

Aluminum:	7.0	Process Control
Cement:	6.0	Process Control
Paper:	10.0	Process Control (a)
Petroleum:	8.0	Process Control
Steel:	6.0	Process Control
Textiles:	5.0	Process Control

Laboratory: AFWAL

Contact: Captain R.R. Preston
Computer Integrated Mfg. Branch
(513) 255-7371

A major effort at AFWAL ML involves computer-aided manufacturing (CAM), which focuses on the disciplined application of integrated computer-aided manufacturing systems to the major functions of manufacturing with the overall goal of increased productivity and flexibility in the manufacturing of defense related material. A long-term goal of this thrust is the reduction in the overhead costs of manufacturing; a reduction of even one percent of total system costs in this area can save billions of dollars.

A primary technical approach is to demonstrate the benefits of the integration of numerous manufacturing application programs (planning, control, decision support, etc.) supported by a common data base and capable of running on numerous computer systems. The successful transition to other companies is the

driving force for the ICAM effort. Major areas of emphasis include manufacturing architecture, fabrication, data base/data automation, design manufacturing interaction, planning and group technology, simulation modeling and operations research, materials handling and storage, and test inspection and evaluation.

To keep industry and universities informed on the various aspects of the overall ICAM Program, several technology transfer activities have been put in place. An example is the annual "Industry Days" meeting. The most recent meeting (June 5-9, 1983 in New Orleans) presented the status of 24 projects that are part of the ICAM Program ranging from the formulation of system development methodologies to the application of robotics technology. Other notable activities planned include presentation of the detail design of an integrated sheet metal center being generated at Boeing Military Airplane Company, a series of short courses on ICAM methodologies, a status report on a computer software "test bed" project, and an ICAM-University linkage workshop. Additionally, an ICAM Product Catalog is published that lists available ICAM reports, films and software.

Reference(s):

1. "Air Force Technical Objective Document FY 1984," AFWAL-TR-82-4201, December 1982. ^(b)
2. "The ICAM Program Report," May 1983. ^(b)

TECHNOLOGY: Coatings

Applicable Industry; Process Element(s):

Cement:	7.0	Safety (accretion removal)
Paper:	11.0	Power Systems ^(a)
Petroleum:	9.0	Safety/Power Systems

Laboratory: AFWAL

Contact: G.F. Schmitt, Jr.
Coatings Area
(513) 255-7377

Coatings work at AFWAL Materials Laboratory is unique to AF mission requirements such as high performance aircraft, space vehicles, geo-synchronous satellites, etc. Its application in industry is not generic but rather to specialized needs, as for example, coatings with properties of thermal flash resistance, antistatic, radar frequency transparent, erosion resistant, or

combinations of these and other properties. Several areas of investigation of potential interest are outlined below.

Laser Stripping of Coatings

Removal of aircraft coatings for maintenance and refurbishment is one of the most significant costs of AF systems and an area in which environmental compatibility, worker safety, and disposability are of concern. A program is underway to explore the feasibility of pulsed CO_2 lasers for coating removal by vaporization without harm to the substrate. The ability to remove 10 microns per pulse and control the pulse rate, pulse length, laydown pattern plus the suitability of commercial-type pulsed lasers make this a promising approach.

Further, the technique has potential off shoots in industry. It could be used to burn out accretions of sticky combustion products, such as those on boiler tubes and other surfaces exposed to particulate/condensable fume laden exhausts. The operation might be conducted without unit shutdown in certain instances or might better be done after shutdown in other instances. A major deficiency is line-of-sight limitation of lasers, but such a system might address particular problems especially well.

CO_2 Pellet Blasting

Another area investigated for removal of coatings is solid CO_2 pellet blasting wherein the removal medium would not require disposal (because it sublimates into the atmosphere). CO_2 pellet blasting was ineffective in removal of some coatings without damaging the fragile aircraft substrates (thin gauge aluminum, glass-epoxy and graphite-epoxy composites). It may be useful where sand or water blasting would harm contained equipment.

Water-Borne Topcoats

A long-range approach to reducing operating and support costs for aircraft and missile coatings is the use of water-borne coatings. A goal is to achieve performance levels comparable to solvent-borne polyurethanes while meeting health and environmental standards and AF standards. Initial activity in this area was the synthesis of resins designed to have solubility parameters that would optimize their compatibility with fluids in use on the aircraft. The

synthesis effort concentrated on anionic and cationic acrylics and urethanes but was only moderately successful with flexibility, a major limitation.

Corrosion Inhibitors

Another coating development area addresses corrosion inhibition, recognizing the expected carcinogenic nature of hexavalent chromium compounds such as zinc chromate and strontium chromate that are the principal inhibitive pigments used today. The developmental effort involves encapsulated (allowing time dependent inhibitor release and/or release of inhibitor when the film is damaged and the capsule is ruptured), and multi-functional (both anodic and cathodic protection) corrosion inhibitive primers. The inhibitive compounds are available, low-cost materials such as nitrites, borates, nitrates and cinnamates, and the encapsulant is nylon resin. In another corrosion protection development, use of corrosion inhibitors in wash water was found to be a good anti-corrosion practice, especially for equipment needing frequent washings.

Reference(s):

1. G.F. Schmitt, Jr., "Spacecraft, Aircraft and Missiles: Pushing the Limits of Coatings," Cleveland Society for Coatings Technology, 26th Conference, April 26-28, 1983^(b)
2. G.F. Schmitt, Jr.^(b) "Coatings for Erosion Resistance," AFWAL Materials Laboratory, n.d.

4.2 BATTELLE PACIFIC NORTHWEST LABORATORIES (PNL)

TECHNOLOGY: Statistically Designed Optimization of a Glass Composition

Applicable Industry; Process Element(s):

Cement: 6.0 Process Control (mixture optimization)^(a)
Petroleum: 7.0 Chemical Treatment

Laboratory: PNL

Contact: L.A. Chick
(509) 375-2121

Finding the component proportions of mixtures that yield optimal material properties is an important activity in materials development. Current methods for developing optimal mixtures, of which there are many, are often inefficient

for mixtures containing three or more components. PNL investigators have developed experimental design and statistical analysis techniques for more efficient development of multi-component mixtures. The mixture development approach, which has successfully been used in formulating special purpose glasses, involves empirical modeling of physical properties as a function of their composition. A composition field is defined, compositions within the field are tested, and the test data are used to fit the empirical models. Empirical models that approximate the true unknown response surfaces are in turn used to specify the optimum glass composition (ingredients recipe). The many-component mixture design capability at PNL is probably unique.

The basic steps employed are listed below for the case of an eight component glass system. The methodology could be effectively applied to many mixture problems.

1. Composition Field Definition. Component variables and their allowed ranges of variation are chosen to define the experimental region of interest. The ranges of variation are chosen by specifying upper- and lower-bounds on the proportion of each component.
2. Testing Composition Selection. Compositions located on the boundary of the composition field provide the most useful information, although compositions in the interior of the field are also desirable and aid in detecting nonlinear behavior of property responses. The test compositions are selected so as to cover the composition field adequately. Some compositions are included several times (replicated) so that the experimental error variance can be estimated.
3. Property Measurements. Materials are manufactured having the Step 2 selected test compositions; properties are measured. Well-defined and controlled measurement procedures are used to keep experimental error to a minimum. Meaningful modeling becomes impossible if experimental error is too large.
4. Empirical Modeling. Polynomial models are often adequate for approximating the true unknown response surface, e.g., second or third order polynomial models fit well for an eight component glass system. Models

based on ratios of components have been found to work well for some mixture situations.

5. Model Verification. Compositions not used in developing the empirical models are manufactured and tested; measured properties are compared to property values predicted for them by the models. This provides an independent verification of the adequacy of the empirical model for approximating the true response surface.
6. Optimization. The verified models are used to specify the composition having the desired/optimum property values.

Reference(s):

1. L.A. Chick and G.F. Piepel, "Statistically Designed Optimization of a Glass Composition," PNL-SA-11040, December 1982.^(b)

TECHNOLOGY: High Electronically Conducting Refractory Oxides

Applicable Industry; Process Element(s):

Aluminum:	7.0	Process Controls
Cement:	6.0	Process Controls
Paper:	10.0	Process Controls
Petroleum:	8.0	Process Controls ^(a)
Steel:	6.0	Process Controls
Textiles:	5.0	Process Controls

Laboratory: PNL

Contact: J. Lambert Bates
Ceramic and Polymers Development
(509) 375-2579

HfO_2 (ZrO_2) - RE_x - In_2O_3 systems are a new class of refractory, highly conductive oxides developed at PNL. The electrical and chemical properties of these systems can be systematically varied by altering their composition and structure. These oxides have high electrical conduction at room temperature and higher, while still retaining good thermal stability in oxidizing atmospheres. Studies have shown that by changing the rare earth element (e.g., Pr, Yb, Tb, Y) and the rare earth and indium oxide concentrations, the electrical conductivity, transport energy, transference number, and crystallographic structures can be modified significantly.

The rare earth, indium and hafnium oxides were initially developed for low-temperature, electrically conducting oxide current leadouts used as electrodes in magnetohydrodynamic electrical generators. Electrical conductivities as high as 20 to 40 mhos/cm at 1000°K were obtained. The oxides exhibited high resistance to electrochemical corrosion in molten potassium carbonate and sulfates and in high temperature molten coal slag containing alkali metal seed when subject to high direct current densities (approximately 1 A/cm²). Methods for fabricating high density oxides for some compositions were developed using coprecipitation of powders and air sintering at temperatures below 1775°K.

A second potential application of these oxides is as cathode electrode materials for molten carbonate fuel cells (MCFC). A problem in MCFC development is the selection of a long lifetime cathode that is highly electronically conducting, corrosion resistant to the 650°C molten alkali metal carbonate electrolyte, stable in high oxygen pressures, and fabricable into thin porous structures. Porous lithiated nickel oxide, the cathode material used in present MCFC designs, degrades when contacted with the carbonate electrolyte at 650°C with a consequent loss of mechanical and electrical stability.

PNL work includes a study of the effects on hafnium oxide and on zirconium oxide of rare earth and indium oxide additions on the electrical, thermal, phase equilibria, corrosion and electrochemical properties of the modified oxides; obtaining a fundamental understanding of how these properties are changed by systematic varying of the composition and rare earth solutions; developing the fabrication methods for these oxides and fabricating materials for testing and evaluation in high-temperature fuel cell and MHD environments and systems. In addition to high-temperature MHD electrodes and MCFC and solid electrolyte electrodes, the highly electronically conducting electrodes have potential application for use in:

- high-temperature pH meters,
- high-temperature photovoltaics,
- high-temperature sensors,
- electronically conducting coatings that are oxidation and corrosion resistant,

- high-temperature thermoelectric generators, and
- high-temperature electronics and semi-conductors.

Reference(s):

1. J.L. Bates and D.D. Marchant, "Highly Electronically Conducting Refractory Oxides," Battelle Pacific Northwest Laboratory. (b)
2. "Oxide Electrodes for High Temperature Fuel Cells," U.S. DOE Field Task Proposal/Agreement, December 21, 1982. (b)

TECHNOLOGY: High Temperature Corrosion and Electrochemical Interactions in Ceramics

Applicable Industry; Process Element(s):

Aluminum:	4.2	Smelting
	5.0	Alloying
Cement:	6.0	Fabrication and Milling
	3.0	Pyroprocessing
Steel:	2.0	Smelting
	3.0	Steelmaking (a)
	4.0	Casting
	5.0	Fabrication

Laboratory: PNL

Contact: J. Lambert Bates
Ceramic and Polymers Development
(509) 375-2579

PNL will study the interactions of refractory, ceramic oxides with the severe thermal, chemical, and electrochemical environments such as molten silicates and salts, reactive gases and electrochemical forces found in many high-temperature processes. The studies are to obtain a basic understanding of the mechanisms of kinetic processes occurring between the refractory oxides and these environments that can be used to develop kinetic and phase equilibrium models. Two principal areas are being investigated:

High-Temperature Corrosion of Ceramics

The liquid-solid dissolution of refractory metal oxides in molten calcium aluminum silicates is being studied to determine corrosion, kinetics and mechanisms. The phase boundary reactions and rate-controlling processes are identified by determining the concentration and distribution of atoms at the reaction

phase boundary. Mass transport and diffusion coefficients are calculated and phase equilibrium and kinetic models developed.

The dissolution of high-purity, single-crystal and polycrystalline oxides, i.e., MgAl_2O_4 , Al_2O_3 , MgO and $\text{Y}_3\text{Al}_5\text{O}_{12}$ in Ca-Al-silicate eutectics containing additions of Fe_2O_3 and MgO is being measured. Initial studies are being conducted in air with subsequent studies to be conducted in the reducing and corrosive atmospheres representative of coal-derived environments.

Electrochemical Interactions in Ceramics

The electrochemical decomposition of ionic- and electronic-conducting oxides and the electrochemical interactions between conducting oxides and molten electrolytes are to be studied. The research will emphasize decomposition kinetics and mechanisms, phase transformations, corrosion kinetics, solid-liquid interface reactions, mass and electrical transport properties that are influenced by the presence of an electric current potential.

Both ionic- and electronic-conducting oxides will be studied as a function of crystallographic structure, composition and stoichiometry. Stabilized ZrO_2 will be studied initially. The electrolytes will be molten alkali metal carbonates and sulfates with eventual inclusion of more complex electrolytes such as molten silicates.

Research on high-temperature corrosion and electrochemical interactions in ceramics has potential application in the following areas:

- Refractories for iron/steel and other metal industries;
- Coal gasification and liquefaction;
- Refractory coatings on metals;
- High-temperature energy conversion systems (i.e., gas turbines, MHD, fuel cells, thermoelectric, and thermoionics);
- High-temperature batteries;
- High-temperature recuperative or regenerative heat exchangers; and
- Refractories for glass industry.

Reference(s):

1. D.D. Marchant, J.L. Bates, L.H. Cadoff, and B.R. Rossing, "Electrochemical Corrosion in Ceramic Materials in MHD Slag/Seed," for U.S. DOE. (b)
2. "High-Temperature Corrosion and Electrochemical Interactions in Ceramics," U.S DOE Field Task Proposal/Agreement, March 1, 1983. (b)

TECHNOLOGY: Sputter Deposition Coating

Applicable Industry; Process Element(s):

Aluminum:	2.1	Crushing
	2.4	Pulverizing
	5.0	Alloying
Cement:	1.1	Quarrying
	2.0	Crushing and Grinding
	5.0	Final Grinding
Paper:	3.1	Harvesting
	4.0	Debarking and Chipping/Grinding
	5.0	Pulping and Bleaching
	6.0	Paper and Paperboard Production
	11.0	Power and Chemical Recovery ^(a)
Petroleum:	2.1	Drilling
	5.0	Separation
	6.0	Conversion
Steel:	5.0	Fabrication

Laboratory: PNL

Contact: Dan Merz
Coatings Research and Technology
(509) 375-2775

PNL has extensive and distinguished capability in high-rate sputtering technology. The sputtering process uses the collision of energetic particles to dislodge atoms from the surface of metallic or nonmetallic targets and deposits them as a uniform film on the material to be coated. PNL researchers have used sputter technology for the high-rate formation of protective coatings and fabrication of free-standing components with thicknesses up to 1/2 inch. Specific applications of sputter technology investigated include depositing amorphous silicon for use in solar cells; developing damage-resistant optical coatings for use on high-energy laser mirrors; developing ceramic, layered metal-ceramic and composition graded metallic materials for use as thermal barriers and corrosion-resistant coatings on gas turbines and heat exchanger components.

Exploratory development of improved transformer cores is the largest current industrial use of amorphous metals. Their use to coat boiler tubes (inside or outside), the Tomlinson boiler used in the pulp and paper industry, for improved corrosion resistance, is an obvious potential application.

TECHNOLOGY: Improved Welding Technology

Applicable Industry; Process Element(s):

Aluminum:	6.2.3	Joining and Finishing ^(a)
Petroleum:	3.0	Transportation
Steel:	5.0	Fabrication

Laboratory: PNL

Contact: J.P. Piler or R. Page
Materials Development
(509) 376-5603

PNL takes a multidisciplinary approach toward solving welding problems. The expertise of welding specialists is supplemented with that of metallurgy, surface science, fracture mechanics, system design, and nondestructive evaluation. Some areas of welding research being investigated by PNL of possible interest to industry are described below:

Electroslag Welding (ES)

Electroslag welding is a relatively new joining process that was developed in Russia, introduced in Europe, and then imported to the U.S. It is similar to a casting process (more so than to a conventional welding process) as the entire cross-section of the joining gap is molten at one time. The making of an ES weld can be viewed as the use of a casting mold comprised of two nonconsumable walls (the cooling shoes) to permit the joining of two consumable walls (the edges of the plates to be welded) by the melting together thereof. Centerline segregation and centerline cracking (typical casting defects) are common in ES welds. ES welds exhibit less toughness and are more susceptible to tension failures than are the more conventional types of weldments; also, the large grain structures in ES welds make it difficult to detect defects using standard nondestructive techniques. Faster welding with thick section weldments is the main advantage of ES welding.

Research is underway at PNL to develop grain refinement and narrow gap welding techniques to increase the fracture toughness in the fusion zone of ES weldments. A ten-fold improvement in both centerline impact resistance and fusion zone grain size, as well as a 50 percent reduction in the width of the heat affected zone have resulted from laboratory investigations. Commercial adaptation of these PNL techniques is expected to provide tougher weld metal and faster welding rates in addition to increased inspectability and weldment

reliability. PNL welding researchers are also currently developing micro-computerized weld monitoring and control equipment for electroslog and other welding processes.

Remote Welding Device

A remotely operated welding device was developed by PNL to seal canisters containing solidified radioactive waste material. The device employs an auto-genous gas tungsten arc welding process in which the welding torch orbits the main body of the welder and thus travels along the joint, eliminating the need to rotate the canister. Remote operation of the welder is required because processing and containment of the waste is carried out in thick-walled radioactive work areas (cells). Control of all weld functions within these cells is performed by remote control from outside the cell walls.

Spotweld Attachment of Thermocouples

PNL has developed novel resistance spot welding systems and tooling to permit attachment of small diameter thermocouples at any position on the internal surface of nuclear fuel rod cladding. The development effort was performed using 0.020 in. diameter Inconel 600 wire, 0.020 in. diameter Inconel 600 sheathed thermocouples, and 0.379 in. outer diameter x 0.022 in. wall Zircaloy 4 cladding. Development was in conjunction with tests to examine deformation and burst behavior of fuel cladding and assess the extent of rod-to-rod interaction in a full fuel bundle cross section under light water reactor loss of cooling accident transient conditions, i.e., under conditions such as were experienced at Three Mile Island.

Evaluation and Acceptance of Welded and Weld Repaired Stainless Steel

Intergranular stress corrosion cracking (IGSCC) of stainless steels requires a combination of a sensitized microstructure, an aggressive environment and tensile stress. Control of any one of these factors can eliminate IGSCC in most practical situations. PNL researchers are developing a methodology for evaluating the acceptance of welded and/or repair welded stainless steel piping by developing validated models, based on experimental data, for predicting the level of sensitization and the IGSCC susceptibility in the heat affected zone of the stainless steel weldments. The prediction model(s) will be based on the cumulative effects of material composition, past fabrication

procedures, and past service exposure, as well as the effect of repair welding and projected component post-repair life.

Reference(s):

1. "Improved Fracture Toughness and Fatigue Characteristics of Electroslag Welds," prepared by Battelle PNL for U.S. DOE, March 1983. (b)
2. R.E. Page, S.O. Bates, and J.P. Pilger, "Spotweld Attachment of Thermocouples to a Fuel Rod Cladding Interior Surface, prepared by Battelle PNL for U.S. DOE, December 1982. (b)

TECHNOLOGY: Surface Science

Applicable Industry; Process Element(s):

Aluminum:	1.0	Mining and Transportation
	5.0	Alloying (corrosion resistant heat exchangers)
Paper:	5.0	Pulping and Bleaching (catalysis for concentration, tube coating for corrosion resistance)
	6.0	Paper Production (corrosion resistant economizers)
	11.0	Chemical Recovery (catalysis for combustion control)
Petroleum:	1.0	Exploring
	5.0	Separation
	6.0	Conversion
	7.0	Chemical Treatment
	9.0	Pollution Control
	10.0	Used Oil (corrosion research)
Steel:	2.0	Smelting (catalysts for low Btu gas combustion, corrosion resistant material)
	3.0	Steelmaking (catalysts for low Btu gas combustion, corrosion resistant materials)
	4.0	Casting (catalysts for low Btu gas combustion, development of corrosion resistant materials)
	5.0	Fabrication (corrosion, erosion resistant materials)

Laboratory: PNL

Contact: Tom Thomas
Technical Leader, Surface Science
(509) 375-2757

Surface Science, a discipline perceived as having little application to technological problem solving in the past, is now met with increasing excitement as a pursuit with both direct and indirect application to solving many

materials related industrial problems. Study of materials surfaces and interfaces can lead to more reliable and longer lived materials in specific environments through improved materials processing and fabrication and through surface treatments (e.g., coatings). It can also lead to greater productivity in industrial processes and improved product quality.

A unique combination of the highest caliber researchers and extensive analytical facilities at Battelle's Pacific Northwest Laboratory make it one of the finest centers for surface science research in the world. Examples of major research thrusts, described in detail below, relates to mineral processing, catalysis, and corrosion.

Mineral Processing

As use of new classes or lower grades of ores increase to meet the demand for mineral products, so do problems with economical prospecting and processing of those ores. For economic processing of precious metal ores in the ppm levels, a number of questions must be answered. For instance, With which mineral phase is the metal associated? Is it in solid solution? Is it associated with carbonaceous matter? Do mineral particles have a refractory coating that make the particles inert to chemical processing? Other areas of concern relate to mineral flotation, flocculation, and product agglomeration, as for example, why one batch of fine particles from a grinding operation will float and a second similar batch will not. Traditional optical and electron microscopy have neither the elemental or surface specificity nor the detection sensitivity to answer these questions. Surface science analytical tools, however, have both the high sensitivity and surface specificity to help provide a solution.

Battelle PNL researchers have examined the application of X-Ray Photoelectron Spectroscopy (XPS), Auger Electron Spectroscopy (AES), and Secondary Ion Mass Spectroscopy (SIMS) to mineral processing problems. XPS can determine both the surface composition and chemistry of ores and tailings, and the various phases within either of them. AES can also determine surface composition with the further advantage of having greater spatial resolution so the surface chemistry associated with the specific minerals in the ore can be identified. This identification helps to clarify why some minerals pass through a chemical process unaffected, while others can be successfully treated. SIMS has an

elemental sensitivity from one to four orders of magnitude greater than XPS or AES, which makes it useful for detecting elements in very low concentration.

Catalysis

Catalysis is a field undergoing explosive development largely due to the application of surface science analytical techniques and instruments. The potential benefits in industrial processes, energy conversion, etc. attendant to the design and optimization of new catalysis and the improvement of old catalysts are enormous. Such instruments provide information on the atomic surface structure of surfaces and adsorbates, electronic structure and oxidation state of surface atoms and adsorbates, electronic structure and oxidation state of surface atoms and adsorbates, and other characteristics useful to understanding catalysts.

Corrosion

Surface analysis can also provide unique information important for understanding corrosion processes and to the solution of corrosion problems. PNL researchers have used surface science techniques to study a number of aspects of corrosion.

1. Corrosion Fatigue

Determining the effect of deformation forces (stress, strain) on adsorption is necessary for full understanding of environmentally enhanced crack growth because adsorption influences embrittlement and crack growth. PNL researchers have examined such effects, specifically H_2S adsorption on iron using Auger electron spectroscopy (AES). A specially designed Ultra High Vacuum (UHV) straining stage allowed samples to be cleaned, aligned, strained and dosed with H_2S in front of the AES analyzer. An applied stress was observed to increase the H_2S adsorption rate on annealed zone-refined iron by as much as 50 percent, suggesting that stress enhanced adsorption could indeed be a factor for environmentally sensitive materials properties such as crack growth and stress corrosion.

2. Corrosion Resistant Alloys

Although the high corrosion resistance of amorphous alloys, such as metalloid stabilized iron-nickel based amorphous alloys, makes them particularly important from both a fundamental and technological point of view, the precise roles of chemistry and structure on the high corrosion resistance are not completely understood. The high corrosion resistance of these materials is usually attributed to the rapid growth of a uniform passive film that easily forms on the alloy. Surface analytical tools, specifically XPS and AES, are useful in studying the passive films and were used by PNL researchers to characterize film and film growth characteristics in different environments (air, pure oxygen, etc.) and to determine optimal use of such instruments. Also studied were the chemistry and function of phosphorous and chromium in the amorphous alloys in promoting corrosion resistance.

3. Stress Corrosion

Still another example of surface science applied to corrosion related research involves the study of the effect of hydrogen, sulfur, and other impurities on the fracture mode and ductility of iron (also nickel). The grain boundary chemistry was determined using AES techniques and this was related to intergranular fracture at various cathodic potentials.

4. High Temperature Oxidation (scale characterization)

A final application of surface science research underway at PNL, also related to corrosion, is the study of the surface chemistry of various iron alloys and stainless steels at high temperatures and under various environments. Examples of some related and ongoing experiments are: the chemistry of alloying elements and impurities (S, O, S, N, and Cl) segregating to defects, free surfaces and grain boundaries in iron alloys; surface chemistry involved in oxide formation on stainless steels, such as 304 stainless steel, and as influenced by grain size, surface treatments (annealing), and O₂ potential; AES and SEM studies of the metallic corrosion process for sputter deposited fine-grained 304 stainless steel at high temperature in a mixed gas environment, especially the influence of Y-doping on oxide formation and study of the attack of protective chromium

oxide by H_2S ; and comparison of the corrosion resistance of fine-grained sputter deposited 304 stainless steel with larger grained conventional wrought samples when exposed to $H_2S-CO-CO_2-N_2$ gas mixtures at $950^\circ C$.

As evidenced from the above paragraphs, PNL maintains a complete surface science facility with a wide selection of analytical equipment. Auger Electron Spectroscopy (AES) is used to identify elemental distributions on surface layers and to develop compositional depth profiles for the studied sample (particularly useful in studying layered structure devices). X-ray Photoelectron Spectroscopy (XPS) is used to determine surface composition and elemental chemistry or valence. Secondary Ion Mass Spectrometry (SIMS) is used to detect elements, especially trace elements, in concentrations as low as 1 part per billion. In addition, with a mass resolution of 1/2 amu and a range of elemental sensitivity from 10 to 10^{-8} atom fraction, SIMS allows accurate isotope identification. Rutherford Backscattering and Nuclear Resonance Spectroscopy are used to provide absolute concentration measurements and to allow fast data collection for depth profiles of thick samples.

References:

1. G.A. Somorjai, "Surface Science," Science, August 1978, pp. 489-497. (b)
2. G.A. Somorjai, W.L. Clinton, and J.T. Yates, Jr., "Surface Science", Materials Science and Engineering, Vol. 35, 1978, pp. 15-31. (b)
3. J. Silcox, et al., "Basic Research Needs and Opportunities for Characterizing the Microstructure and Microchemistry of Interfaces," Materials Science and Engineering, Vol. 53, 1982, pp. 149-162. (b)
4. C. Rain, "Surface Magic: Making Metals Tougher," High Technology, March 1983, pp. 59-64. (b)
5. M.T. Thomas, et al., "Application of Surface Science Spectroscopies to Interfacial Problems in Mineral Processing," for Proceedings of Engineering Foundation Conference on Interfacial Phenomena in Mineral Processing, Rindge, NH, August 1981. (b)
6. T.H. Maugh, "Catalysis: No Longer a Black Art," Science, February 1983, pp. 474-477. (b)
7. D.R. Baer and M.T. Thomas, "Use of Surface Analytical Techniques to Examine Metal Corrosion Problems," ACS Symposium Series No. 199, 1982. (b)
8. S.D. Dahlgren, J.W. Patten, and M.T. Thomas, "The Metallurgical Characterization of Coatings," Int'l Conf. on Met. Coatings. San Francisco, CA, April 3-7, 1978. (b)

9. D.R. Baer, M.T. Thomas, and R.H. Jones, "Influence of Stress on H₂S Adsorption on Iron," BPNL, January 1983, submitted to Metallurgical Transactions. (b)
10. D.R. Baer and M.T. Thomas, "AES and XPS Analysis of Corrosion Layers Formed on Amorphous Fe Cr Ni Pb," BPNL, n.d. (b)
11. D.R. Baer, "Protective and Non-Protective Oxide Formation on 304 Stainless Steel," Applications of Surface Science, Vol. 7, 1981, pp. 69-82. (b)
12. D.R. Baer and J.T. Prater, "AES and SEM Studies of Oxide and Sulfide Scales Formed on Sputter Deposited 304 Stainless Steel at 800 and 950°C," J. Vac. Sci. Tech., April 1982, pp. 1396-1399. (b)
13. J.T. Prater and D.R. Baer, "Improved Corrosion Resistance of Fine Grained 304 Stainless Steel in H₂S-CO-CO₂-N₂ Atmospheres," Proc. of Symp. on Corrosion in Fossil Fuel Systems, Electrochemical Soc., October 1982. (b)

TECHNOLOGY: Stress Corrosion Research

Applicable Industry; Process Element(s):

Aluminum:	8.0	Safety
Cement:	7.0	Safety
Paper:	12.0	Safety
Petroleum:	9.0	Safety (a)
Steel:	7.0	Safety
Textiles:	6.0	Safety

Laboratory: PNL

Contact: Russ Jones
Metallurgy Research Section
(509) 376-0120

Emphasis of stress corrosion work at PNL is on basic research, particularly on microstructure and microchemistry effects. Individual and comparative studies have been performed to examine grain boundary chemistry, fracture mode, and ductility of iron and nickel tested at cathodic potentials and as influenced by impurities (e.g., sulfur, phosphorous, antimony). For nickel, sulfur as an impurity was found to be very active in promoting intergranular attack, and, in a proper environment, hydrogen embrittlement. A direct relationship was found between grain boundary sulfur coverage and cathodic potential, each promoting a change in fracture mode to intergranular and a sharp loss of ductility. This behavior exemplifies the cooperative interaction between a grain boundary segregant and hydrogen embrittlement. Phosphorous addition to nickel, however, reduced the tendency for intergranular fracture; it also improved ductility. In systems with both phosphorous and sulfur present, phosphorous

segregation restricted sulfur enrichment of grain interfaces, thus making the sulfur less potent in promoting intergranular fracture.

Critical sulfur concentrations (defined as the grain boundary sulfur concentration corresponding to 50 percent intergranular fracture) were determined and were found to depend inversely on the hydrogen pressure. It has been suggested that grain boundary impurities effect the hydrogen embrittlement rate, without altering the embrittlement process, although this result does not indicate whether decohesion or plasticity dependent processes are responsible for the combined sulfur-hydrogen effect.

In other stress corrosion work, 304 stainless steel samples sputter coated with an amorphous layer were tested in $MgCl_2$ at $155^{\circ}C$. A 30 percent improvement over bulk uncoated material stress corrosion rates was found. Although predictable for unstressed samples, the improvement is significant for stressed samples.

References:

1. S.M. Bruemmer, R.H. Jones, M.T. Thomas, and D.R. Baer, "Influence of Sulfur, Phosphorous, and Antimony Segregation on the Intergranular Hydrogen Embrittlement of Nickel," *Met Trans.*, February 1983. ^(b)
2. R.H. Jones, S.M. Bruemmer, M.T. Thomas, and D.R. Baer, "Effect of Sulfur and Antimony on the Intergranular Fracture of Iron at Cathodic Potentials," *Met. Trans.*, February 1982. ^(b)
3. R.H. Jones, S.M. Bruemmer, M.T. Thomas, and D.R. Baer, "Comparison of Segregated Phosphorous and Sulfur Effects on the Fracture Mode and Ductility of Iron Tested at Cathodic Potentials," *Scripta Metallurgica*, Vol. 16, 1982. ^(b)
4. R.H. Jones, S.M. Bruemmer, M.T. Thomas, and D.R. Baer, "Hydrogen Pressure Dependence of the Fracture Mode Transition in Nickel," *Met. Trans.*, (in press). ^(b)

TECHNOLOGY: High-Temperature, High-Pressure Electrochemical Probes

Applicable Industry; Process Element(s):

Aluminum:	7.0	Process Control
Cement:	6.0	Process Control
Paper:	10.0	Process Control
Petroleum:	8.0	Process Control
Steel:	6.0	Process Control
Textiles:	5.0	Process Control

Laboratory: PNL

Contact: M.J. Danielson
Senior Research Scientist
Corrosion Research and Engineering
(509) 376-5941

PNL researchers in the corrosion research and engineering laboratory have developed electrochemical probes and analytical methods for a wide range of industrial process control needs. Probes are better than off-line analysis techniques for monitoring chemical solutions because as on-line instruments they do not require interrupting system operation to obtain samples. Further, conventional techniques frequently require that the sample be cooled and depressurized before analysis; this may irreversibly alter sample chemistry. Described below are three electrochemical probes developed and in use at PNL. All can operate under extreme pressure conditions involving high-temperatures (300°C) and high pressures (5,000 psi).

High Temperature pH Probes

PNL has developed a device for measuring pH at high temperatures (95°C and up), the first electrochemical probe to ever measure pH at elevated temperatures. The pH element is yttrium stabilized zirconia. The probe requires a reference electrode to use; this too has been developed. The pH probe is a very high impedance device; the high impedance imposes a lower temperature limit on the device by lowering response times. A similar device is currently used in the steel industry. The caustic chlorine industry could also benefit from such a probe.

Electrodeless Conductivity Probe

An electrodeless conductivity probe (ECP) has been designed and tested at temperatures up to 250°C and pressures of 600 psi. A unique pressure seal permits temperature cycling. Design of the electronics permits accurate measurement of conductivities at various elevated temperatures in spite of the change of magnetic properties of the toroids with temperature. The design of the probe can be adapted for insertion in-line, or for bypass operation.

The electrodeless system measures the resistance of a closed loop of solution by determining the amount of coupling between driver and pickup toroidally wound coils arranged around the solution loop. The ECP requires a break in the metal casing housing the coils, or the case will act as a shorting loop in

parallel with the solution loop. An insulating pressure seal is required to break the short and prevent high pressure liquid from entering the coil compartment. A ceramic tube inserted inside the spool piece and held in place by the seal determines the cell constant.

Reference Electrode Probe

PNL researchers have also developed a long-lived reference electrode for difficult high-temperature/pressure environments. The reference electrode is an improved version of earlier high-temperature, high-pressure Ag/AgCl electrodes that were resistant to the contaminating effects of H_2 and H_2S . The external reference electrode suffers from a thermal liquid junction potential (TLJP) and the development of the Soret Effect (thermodiffusion of the electrolyte). However, the TLJP rapidly stabilizes and the Soret Effect is extremely slow to develop (when KCl is used); consequently, the potential of external reference electrode can be placed on the hydrogen scale and can function as successfully as a truly thermodynamic model. Tests with the earlier design in the geothermal field indicated a life of greater than six months under some conditions (steady pressure of 400 psig, $170^{\circ}C$) but a life of 1 to 2 weeks when the pressure fluctuated widely ($P = 100$ psig, $70^{\circ}C$). Pressure fluctuations result in a pumping action that transfers outside test solution into the reference electrode compartment; degradation is due to dilution effects or reaction of the Ag/AgCl with the contaminants brought into the compartment. The improved reference electrode is the same as the earlier model except that a silvered-tube replaces the silver wire electrode. A liquid chromatograph mini-pump (flow rate = 0 to 90 ml/hr) slowly injects fresh KCl solution into the reference electrode to maintain a front of fresh solution. A flow rate of about 1 ml/hr generally prevents the aging effects of earlier models.

References:

1. M.J. Danielson, "A Long-Lived External Ag/AgCl Reference Electrode for Use in High Temperature/Pressure Environments," January 1983 (for Corrosion Journal).^(b)
2. O.H. Koski and M.J. Danielson, "Design and Construction of a High Temperature and Pressure Electrodeless Conductivity Probe," Rev. Sci. Instruments, November 1979.^(b)

TECHNOLOGY: Nondestructive Evaluation (NDE)

Applicable Industry; Process Element(s):

Aluminum:	8.0	Safety
Cement:	7.0	Safety
Paper:	12.0	Safety
Petroleum:	9.0	Safety
Steel:	7.0	Safety
Textiles:	6.0	Safety

Laboratory: PNL

Contact: J.L. Bates
Ceramic and Polymers Branch
(509) 375-2579

Nondestructive evaluation is one of several areas of expertise at PNL that is used in addressing materials reliability problems. Others are metallurgy, fracture mechanics, structural and stress analysis, electronics, computer technology, chemistry, corrosion, welding, chemical engineering, and ceramics engineering. Nondestructive evaluation detects, locates and characterizes flaws in all types of materials while the component or structure is still in service, if necessary, and often before the flaw is large enough to be detected by more conventional means. Below are brief descriptions of nondestructive evaluation methods.

1. Radiography

Radiography is the most frequently used nondestructive test method. X-rays and gamma rays passing through a structure are absorbed differently by flaws or inconsistencies in the material. Cracks, voids, porosity, dimensional changes, and inclusions can be viewed on the resulting radiograph.

2. Ultrasonic Testing

In ultrasonic testing the sound waves from a high-frequency ultrasonic transducer are beamed into the material. Discontinuities in the material that interrupt the sound beam reflect energy back to the transducer, providing data that can be used to detect and characterize the flaws.

3. Eddy Currents

When an electromagnetic field is introduced into an electrical conductor, eddy currents flow in the material. Variations in material conductivity

caused by cracks, voids, metallurgical changes, or thickness changes can alter the path of the eddy current. Probes are used to detect the current movement and thus describe the flaws.

4. Acoustic Emission

When flaws or cracks grow, minute amounts of elastic energy are released and propagate in the material as an acoustic wave. Sensors placed on the surface of the material can detect these acoustic waves, providing information about location and rate of flaw growth. These principles form the basis for the acoustic emission test method.

5. Liquid Penetrant

The liquid penetrant method is used to identify surface flaws and cracks. Special low-viscosity fluids containing dye, when placed on the surface of a part, penetrate into the flaw or crack. When the surface is washed, the residual penetrants contained in the part reveal the presence of flaws.

6. Magnetic Flux Field

A magnetic flux field is developed when an electric current or external magnetic force is applied to a ferritic material. Flaws disrupt the magnetic path and set up a field pattern around the flaw. When the surface is dusted with finely divided ferritic materials, the area around the flaw is revealed.

7. Acoustical Holography

In acoustical holography, computer reconstruction provides the means for storing and integrating several holographic images. A reconstructed stored image is a three-dimensional picture that can be electronically rotated and viewed in any image plane. The image provides full characterization and detail of buried flaws.

General NDE research at PNL is aimed at:

- Improvements in available technology;
- Improved data processing;
- Instrumentation and procedures for imaging flaws using ultrasonic eddy current and acoustic emission energies; and

- Generation of engineering values describing the capabilities of non-destructive measurement.

Imaging of flaws is a major research activity. Acoustical holographic imaging, both computer reconstruction and real-time liquid surface is by far the most advanced. Eddy current imaging is undergoing initial laboratory demonstrations, and the feasibility of acoustic emission imaging has been established. Other research projects involving NDE include development of a micro-processor controlled ultrasonic flow detectors, a chirp-frequency ultrasonic testing system for determining impact damage on composites, studies to determine quality of epoxy- and metal-matrix composites, in-flight acoustic emission monitoring of aircraft structures, on-line monitoring of nuclear reactor pressure vessels and piping, and microwave eddy-current systems for detecting cracks in critical aircraft engine components.

References:

1. R. Clark, G. Posakony, and M. Bampton, "Solving Materials Reliability Problems," Battelle Today, No. 30, November 1982. (b)

TECHNOLOGY: Full-Scale Pipe Test Facility

Applicable Industry; Process Element(s):

Aluminum:	8.0	Safety
Cement:	7.0	Safety
Paper:	12.0	Safety
Petroleum:	9.0	Safety ^(a)
Steel:	7.0	Safety
Textiles:	6.0	Safety

Laboratory: PNL

Contact: Bill Anderson
(509) 946-3637

Intergranular stress corrosion cracking (IGSCC) in the weld affected zone of stainless steel piping can impact plant availability and is of increasing concern to the nuclear industry. Causes of this cracking have been identified and alternatives for remedial action are under development. Some stainless steel samples revealed depletion of corrosion inhibiting elements in the weld affected zones. Concurrent with research into causes and development of

remedies for pipe cracking, tests have been developed to demonstrate the effectiveness of remedies.

A large-scale pipe testing facility at PNL's Material Reliability Center is used in conducting these and other tests. The testing facility is capable of testing 6-foot lengths of 2-foot diameter, 1 1/2 inch wall thickness pipes. Pipe testing equipment includes a 20-ton capacity crane with 25-foot hook height; pipe test fixtures capable of subjecting pipes to axial loading (up to 4 million pounds tensile or 2 million pounds compressive), simultaneous bending, and cyclic computer controlled hydraulic loading, and water loops that permit independent control of water chemistry, pressure (up to 1500 psi) and temperature (up to 290°C). An attached laboratory support building is equipped with systems for computer controlled data acquisition and analysis, and nondestructive evaluation as described separately.

Recent research using the test facility involved the determination of the effectiveness of a heat sink welding technique in suppressing crack initiation and crack growth that lead to IGSCC in a reference weld made by normal procedures. This IGSCC remedy, termed last pass heat sink welding, changes the residual stress on the inner surface of a weldment from tension to compression, a change that will tend to inhibit IGSCC. An experimental assessment of the technique as an in-field large pipe weldment repair method is in process.

References:

1. N.J. Olson, W.E. Anderson, and J.D. Gilman, "Testing of Large Diameter Pipe in a Simulated BWR Environment to Evaluate Stress Corrosion Cracking Resistance," TANSO, Vol. 39, 1981.

TECHNOLOGY: High Pressure/High Temperature Autoclaves and
Pipe Test Facilities

Applicable Industry; Process Element(s):

Aluminum:	8.0	Safety
Cement:	7.0	Safety
Paper:	12.0	Safety ^(a)
Petroleum:	9.0	Safety
Steel:	7.0	Safety
Textiles:	6.0	Safety

Laboratory: PNL

Contact: R. A. Clark
Mgr., Corrosion Research and Engineering
(509) 376-0174

Battelle PNL maintains extensive high-pressure, high-temperature, autoclaves and pipe-test facilities including constant extension rate, constant load, and cyclic fatigue devices. These facilities are used for corrosion, stress-corrosion cracking, and tube pressure capability; development of non-destructive crack detection and crack growth measurement techniques; and leak rate measurements.

Autoclaves range in size from 300 cc to 95 gallons, with diameters from 1-3/4 to 18-1/2 inches and depths to 7 feet. Vessel materials include Hastelloy C-276; Inconel 600 and 625; titanium codes 2, 7, and 12; zirconium; nickel 200; and 316 and 347 stainless steel. Pressure and temperature capabilities extend to 20,000 psig and 1250°F. Test operations are supported by centralized and batched water treatment facilities and a well-equipped analytical laboratory. Water systems allow duplication of the water chemistries of special test environments, such as those for reactor coolants, geothermal brines, or ground water.

Pipe-test facilities include a project demonstration loop with a flow-rate capacity of up to 150 gpm at 650°F and 2500 psig. The loop can supply hot flowing water to a series of pipe test stands. The test stands can apply to each specimen a programmed cyclic tensile load of up to 100 tons. The demonstration loop has been used to test weldments on 4-inch schedule 80 stainless steel pipe at 550°F, 1200 psig, with a cyclic load up to 150 percent of the 550°F yield strength of the test weld.

Another test loop has been operated at 550°F, 1200 psig and can apply up to two million pounds of axial load hydraulically to 26- to 28-inch schedule 80 pipe specimens. Two larger test stands can accommodate up to 28-inch pipe and supply cyclic programmable loads of up to four million pounds tensile or two million pounds compression. Additional test loop facilities capable of use with solutions containing sulfur and chlorides are also available.

TECHNOLOGY: Cable Tester

Applicable Industry; Process Element(s):

Aluminum:	8.0	Safety
Cement:	7.0	Safety
Petroleum:	9.0	Safety ^(a)
Steel:	7.0	Safety

Laboratory: PNL

Contact: Lowell Strobe
(509) 375-2121

PNL has designed and built the largest wire rope fatigue tester in the world. The tester was built for the U.S. Bureau of Mines and has been used in solving problems associated with the dragline used in mining operations. For example, comparative fatigue performance data for large (3 to 5 inch) and small (1/2 to 1 1/2 inch) diameter ropes were obtained using the tester. Comparison of load, sheave diameters, rope diameter and wire material lead to correlations between behavior of large and small diameter ropes so that economical small rope research could be used to predict large-rope behavior and extend large rope life.

Although no longer in use, the facility could be of interest to the petroleum industry, particularly for drilling operations and for the mooring production platforms via tension cables (in 2000 ft. of water). Another capability of the facility, testing structural pipe as to influences for strength of eccentricity (out of roundness) and wall thickness variations, is of potential interest to builders of column stabilized platforms for the oil industry.

References:

1. "Full-Scale Structural Integrity Testing Evaluation," Battelle Pacific Northwest Laboratories, April 1979.^(b)

4.3 NATIONAL AERONAUTICS AND SPACE ADMINISTRATION MARSHALL SPACE FLIGHT CENTER (NASA MARSHALL)

TECHNOLOGY: Variable Polarity Plasma Arc Welding

Applicable Industry; Process Element(s):

Aluminum:	6.2.3	Joining and Finishing ^(a)
Petroleum:	3.0	Transportation
Steel:	5.0	Fabrication

Laboratory: NASA Marshall

Contact: E. Bayless
Material Processes Branch
(205) 453-0011

NASA Marshall's Metal Processing Division has developed a Variable Polarity Plasma Arc Welding (VPPA) technology capable of joining heavy gage aluminum. VPPA welding operates at 19 milliseconds/4 milliseconds cycling of polarity that results in cathodic cleaning of areas being joined. This technology offers the significant advantages of reduced precleaning requirements, reduced distortion, and improved internal weld quality. It has proven to be far superior to tungsten inert gas (TIG) welding and more versatile than electron (EB) welding. Although VPPA welding has not been explored by NASA on metals other than aluminum, it is eventually expected to replace the TIG method now used in fabricating the Space Shuttle External Tank. Hobart Power Supply is the current equipment manufacturer.

TECHNOLOGY: Computer Modeling/Control of Welding

Applicable Industry; Process Element(s):

Aluminum:	6.2.3	Joining and Finishing ^(a)
Petroleum:	3.0	Transportation
Steel:	5.0	Fabrication

Laboratory: NASA Marshall

Contact: A. C. Nunes, Jr.
Material and Processes Laboratory
(205) 453-0011

With sufficient development, computer modeling/control of welding is expected to become a tool to quickly specify the weld machine parameters (i.e., the power setting and welding rate-in./min.) that yield a superior weld for specific material. Art Numes described and demonstrated such a model presently under development. To obtain the power setting and welding rate, the model requires: 1) alloy data such as the heat transfer/thermal properties of the alloy; 2) point or line source power input (e.g., TIG is point source and EB is line source of heat); 3) desired weld profile (route width, bead geometry); and 4) material thickness. Currently, the model is limited in that it can only handle those materials that are thermally modeled. However, the program will eventually be developed such that when the required metallurgical properties of the weld are specified, e.g., grain structure, heat effected zone, percent voids/inclusions, the required welding parameters and the combination of weld machine settings that yield the welding parameters can be specified.

References

1. A.C. Numes, Jr., "Energy: Arc and Beam Welding Processes," 1982 ASEE Southeastern Section Meeting Proceedings, 1982.^(b)
2. A.C. Numes, Jr., "An Extended Rosenthal Weld Model," n.d.^(b)

TECHNOLOGY: Bearing Tests Data Base

Applicable Industry; Process Element(s):

Aluminum:	2.1	Crushing
	2.4	Pulverizing
Cement:	2.0	Crushing and Grinding
	5.0	Final Grinding
Paper/Allied Products:	3.1	Harvesting
	4.0	Debarking and Chipping/Grinding
	5.1	Mechanical Pulping
Petroleum:	2.0	Drilling and Recovery
Steel:	5.0	Fabrication
Textiles:	2.0	Yarn Making
	3.0	Fabric Construction ^(a)

Laboratory: NASA Marshall

Contact: F. J. Dolan
Lubrication and Surface Physics Branch
(205) 453-1504

NASA Marshall's Lubrication and Surface Physics Branch defines mission requirements for bearings and lubricants (or is presented with mission requirements) and qualifies alternative solutions to meeting those requirements through experimental testing. As a result, the laboratory has accumulated a substantial experimental data base on bearings and lubricants. The data base provides information for such parameters as coefficients of friction between many different materials, different loads, different surfaces finishes and different lubricants under specific loadings/environments. Materials couples tested include 440C, BG42, inconel, waspaloy, incaloy, aluminum to titanium, also, steel. This continually expanding data base could be of significant value to industrial equipment designers, but has not been published.

TECHNOLOGY: High-Speed Machining

Applicable Industry; Process Element(s):

Aluminum: 6.2 Milling^(a)
Steel: 5.0 Fabrication

Laboratory: NASA Marshall

Contact: Don Lakey
Technology Utilization Office
(205) 453-2224

Lockheed Missiles and Space Company, Inc., under contract to NASA Marshall Space Flight Center, evaluated the potential application and advantages of applying high-speed machining techniques to the milling of space shuttle external fuel tank panels. Because the external fuel tank is not recovered after launch, less costly production is advantageous. Selected sample portions of an external tank panel were machined, and data from the high-speed machining of the sample panel sections were used to project procedures and times for high-speed machining of an entire panel when using optimal equipment.

During demonstration of high-speed machining of a 4 foot long, 2219-T87 aluminum alloy panel section, a cutting speed of 5,890 surface feet per minute (sfpm) was witnessed when using a 1 1/4 in. diameter roughing and finishing cutters turning at 18,000 rpm. A table feed rate of up to 200 inches per minute (ipm) (the maximum machine capability) was observed while removing up to 56 cubic inches/minute of material with the roughing cutter and utilizing most of

the 16.6 horsepower available from the spindle motor. Applicable parameters for the finishing cutter include a feed rate of 130 ipm and a metal removal rate of 25 cubic inches/minute. For a 4-inch diameter T-rib cutter cutting at 8,378 sfpm (8,000 rpm), a table feed rate of 100 ipm and removal rate of 18 cubic inches/minute were observed. Because chips were small and had a tightly rolled shape, problems with chip removal were not anticipated. A conveyor system with flood coolant or air blast nozzles to move chips to a conveyor or even the use of a vacuum system was recommended for full-sized panels. Examination of cutter wear characteristics showed little or no wear.

It was concluded that high-speed machining techniques used in Lockheed's missile production were transferable to the manufacture of portions of shuttle external tank panels. It was projected that with properly designed equipment, metal removal rates up to 300 cubic inches/minute could be achieved and an entire shuttle panel (11 ft x 20 ft) could be high-speed machined in as little as 6 hours using equipment currently available. Even less time was projected using equipment for which technology to build is now available.

References:

1. J.A. Miller, "Task 8 Final Report: High-Speed Machining of Space Shuttle External Tank Panels," prepared by Lockheed Missiles and Space Company, Inc. for NASA Marshall Space Flight Center, September 1982. (b)

TECHNOLOGY: Stress Corrosion Testing Program

Applicable Industry; Process Element(s):

Aluminum:	8.0	Safety
Cement:	7.0	Safety
Paper/Allied Products:	12.0	Safety (a)
Petroleum:	9.0	Safety
Steel:	7.0	Safety
Textiles:	6.0	Safety

Laboratory: NASA Marshall

Contact: D.B. Franklin
Chief, Corrosion Research Branch
(205) 453-5872

Since its inception 25 years ago, the Stress Corrosion Testing Program at NASA Marshall has investigated the stress corrosion characteristics of a wide variety of materials. Tests have been performed on numerous aluminum, steel,

nickel, copper, and ferrous alloys under both fresh and sea water atmospheric conditions. The impact of various coatings on stress corrosion has also been investigated. There exists an extensive data base on the stress corrosion of nearly 50 different materials when exposed to a sea coast atmosphere (5% salt concentration). The data base may be of interest to the steel and aluminum industries as well as to others, but has not been published.

TECHNOLOGY: Low Gravity Microsegregation Behavior

Applicable Industry; Process Element(s):

Aluminum: 5.0 Alloying
Steel: 4.0 Casting^(a)

Laboratory: NASA Marshall

Contact: Ron Snyder
(205) 453-3537

A major goal of NASA's Materials Processing in Space (MPS) program is to use the low-gravity environment of space to vastly reduce or eliminate hydrostatic pressure, sedimentation, buoyancy driven convection, and in some cases, container walls in the processing of materials. Ultimately, it is expected that new processes or products will emerge that will have sufficient value to justify the cost of processing them in space. More immediate use of the low-gravity environment is as a research tool to increase understanding of process control, and particularly the effect of gravity, of various terrestrial processes. The MPS program is currently (November 1982) sponsoring some 60 investigations at a number of universities, private corporations, and government laboratories. The total program is summarized in "Materials Processing in Space Tasks," NASA TM-82443, published by MSFC. Investigations conducted at MSFC over the past several years, and representative of those supported by the program, include crystal growth and characterization, undercooling studies in metastable peritectic compounds, model immiscible systems, crystallization studies of borderline glass formers, electrophoresis, and phase partitioning.

One aspect of low-gravity materials research at NASA Marshall is the study of solidification characteristics, particularly micro-segregation behavior of alloys as a function of gravity. The laboratory has participated in ten

launches of the Space Processing Applications Rocket (SPAR), which provided 3 to 5 minutes of low-gravity experimentation. Molten alloy is sent aloft in heated crucibles, frozen with liquid nitrogen to freeze low-gravity effects, and studied for microsegregation, etc. Centrifuge experiments are also conducted. Under Contract to NASA Marshall, General Electric is using data obtained in such experiments in developing interactive computer software for predicting microsegregation behavior.

References:

1. "Research and Technology," Annual Report Fiscal Year 1982, George C. Marshall Space Flight Center, Research and Technology Office, November, 1982.^(b)
2. "Materials Processing in Space Tasks," NASA TM-82443.

TECHNOLOGY: Turbine Blade Coating Process

Applicable Industry; Process Element(s):

Aluminum:	1.0	Mining and Transportation ^(a)
Cement:	1.0	Quarrying and Transportation
Paper/Allied Products:	3.0	Timber Harvesting
Petroleum:	3.0	Transporting

Laboratory: NASA Marshall

Contact: R.L. Nichols
Ceramics and Coating Research
(205) 453-1222

To obtain the potential benefits of improved space shuttle main engine (SSME) performance safety, increased producibility and reduced engine maintenance costs, NASA Marshall is investigating coating processes and the performance of various coatings. Turbine blades, vacuum plasma spray coated with NiCrAlY, CoCrAlY or NiCrAlY/Cr₂O₃ under contract with Howmet Corporation were evaluated and rated superior to standard SSME coated blades. Ratings were based primarily on 25 thermal cycles in the MSFC Burner Rig Tester. This test showed there was no spalling on blades with improved coatings, while standard blades spalled. ZrO₂ thermal barrier coatings are being applied on top of the "M" CrAlY bond coatings. Fatigue and tensile specimens, machined from MAR-M-26 test bars, identical to the turbine blades, are being vacuum spray coated

and diffusion bond treated to qualify the vacuum plasma spray process for flight hardware application.

Reference:

1. "Research and Technology," Annual Report, Fiscal Year 1982, George C. Marshall Space Flight Center, Research and Technology Office, November 1982.^(b)

TECHNOLOGY: Preparation of Silicon Carbide-Silicon Nitride Fibers

Applicable Industry; Process Element(s):

Aluminum:	1.0	Mining and Transportation
	6.0	Fabrication and Milling (heat exchangers)
Cement:	1.0	Quarrying and Transportation
Steel:	4.0	Casting (heat exchangers)
	5.0	Fabrication (heat exchangers) ^(a)

Laboratory: NASA Marshall

Contact: R.L. Nichols
Ceramics and Coating Research
(205) 453-1222

The need for high-performance, low-weight and low-cost parts for use in aircraft and missile construction has prompted efforts to develop new reinforcement fibers for use in composite materials. NASA Marshall, based on a method developed by Verbeek, investigated a technique for producing polycarbosilazane resin and high-strength silicon carbide-silicon nitride ($\text{Si}_x \text{N}_y \text{C}_z$) fibers. These fibers are potential candidates to replace presently used carbon fibers, which suffer from high electric conductivity, a property of safety concern in manufacture, application, and disposal.

In this study, NASA Marshall researchers prepared $\text{Si}_x \text{N}_y \text{C}_z$ fibers by pyrolysis of polysilazane precursors, prepared by heating tris (N-methyl-amino) methylsilane. Also, the effects of reaction time and temperature on the molecular weight, the relationship of tensile rupture modulus to fiber diameter, and electrical resistivity properties were examined. The results have indicated that $\text{Si}_x \text{N}_y \text{C}_z$ fibers are comparable to other high-strength fibers in terms of mechanical properties. For example, its tensile modulus (29×10^6 psi) is comparable to that of other reinforcement fibers such as alumina, boron nitride, silicon carbide, and graphite, which have

tensile module of 25, 12, 65 and 55 x 10⁶ psi, respectively. However, the electrical resistivity value of silicon carbide-silicon nitride is about 10¹² greater than that obtained for graphite.

Reference:

1. B.G. Penn, et al., "Preparation of Silicon Carbide - Silicon Nitride Fibers by the Controlled Pyrolysis of Polycarbosilazane Precursors," Journal of Applied Polymer Science, Vol. 27, 1982, pp. 3751-3761. (b)

TECHNOLOGY: Adhesive Bonding

Applicable Industry; Process Element(s):

Aluminum:	4.0	Smelting
	5.0	Alloying
Cement:	3.0	Pyroprocessing
Paper/Allied Products:	5.0	Pulping and Bleaching
	6.0	Paper and Paperboard Manufacture
Petroleum:	5.0	Separation
	6.0	Conversion
Steel:	3.0	Steelmaking (a)
	4.0	Casting
	5.0	Fabrication

Laboratory: NASA Marshall

Contact: J. M. Stuckey
Polymers and Composite Branch
(205) 453-1228

Jack Stuckey reviewed NASA Marshall's unique capability in bonding of materials that must withstand extreme environments, such as thermal gradients associated with re-entry pulses and cryogenic tanks. Bonding insulation on the AFT skirt of the space shuttle solid rocket booster and bonding instrument islands to the LO_x tank of the space shuttle external tank are among the potential uses of adhesive bonding materials of interest to NASA investigators. Potential industrial applications include bonding insulation to cryogenic tanks and lines that may be exposed to elevated temperatures. An example of research in this area is the evaluation of the properties of polyurethane resins and adhesives. Various formulations using Dupont liquid urethane resins (Adiprene L-100, Adiprene L-315) and Hysol EA 9322 A resin and Hysol 9322 B activator (emulsion) were investigated. Dupont's Adiprene L-315 polyurethane resin with Hysol EA-9322 B activator was shown to cure at room temperature and

give useful bond strength over the temperature range of -184°C to $+149^{\circ}\text{C}$. The activator mixed with the liquid polyurethane resin provides an easily processible system with a pot life in excess of one hour.

References:

1. J.M. Stuckey, "Polyurethane Adhesive with Improved High Temperature Properties," ASPE/MSFC Symposium: Engineering and Productivity Gains from Space Technology Proceedings, May 1977, pp. 147-152. (b)

TECHNOLOGY: Development of Urethane Coating and Potting Material

Applicable Industry; Process Element(s):

Paper/Allied Products:	10.0	Process Control ^(a)
Petroleum:	8.0	Process Control
Steel:	6.0	Process Control

Laboratory: NASA Marshall

Contact: J.M. Stuckey
Polymers and Composites Branch
(205) 453-1228

One of the most severe deficiencies of polyurethanes as engineering materials for electrical applications is their sensitivity to combined humidity and temperature environments. To gain a better understanding of the mechanisms and interactions of moisture in urethane, NASA Marshall began a comprehensive study that has led to the development of urethane materials with improved hydrolytic and oxidative stabilities.

In this effort, a series of saturated hydrocarbon-based urethanes was prepared and characterized for hydrolytic and oxidative stability. A series of ether-based urethanes was used as a basis for comparison. The alkane-based urethanes were found to be hydrolytically and oxidatively stable, and had excellent electrical properties. The alkane-based materials absorbed little or no water and were reversion-resistant. There was little loss in hardness or weight when exposed to high temperature and humidity. Dielectric properties were excellent and suffered little adverse effects from the high-temperature/humidity conditions. The alkane-based urethanes were not degraded by ozone exposure.

References:

1. D.E. Morris, "Development of Urethane Coating and Potting Material with Improved Hydrolytic and Oxidative Stability, NASA Technical Memorandum, NASA TM-82408, March 1981.

TECHNOLOGY: Firefighting Module Development

Applicable Industry; Process Element(s):

Paper/Allied Products: 2.3 Yield Management
(firefighting, emergency pumping)
Petroleum: 9.0 Health, Safety and Pollution Control
(offshore fire fighting, oil spill cleanup)^(a)

Laboratory: NASA Marshall

Contact: R.A. Burns
Structures and Propulsion Laboratory
(205) 453-5706

A lightweight, helicopter-transportable, firefighting module, designed to improve harbor fire protection for inland and coastal waterways, has been developed by NASA Marshall. The module is unique in its lightweight, compact size (1600 lb. dry), helicopter transportability to a fire site, self-contained fuel supply, 2,500 gal/min. flow capability and its ability to draft water up to a 20-foot elevation above the sea. The module was developed in a jointly sponsored project funded by the U.S. Coast Guard and the Maritime Administration. It consists of a lightweight, two-stage aerospace-type pump that is driven by a 370 hp gas turbine engine. The unique design used in the development of the module enables it to be deployed in a number of potential applications, which include:

- fire boat,
- fire truck,
- forest fires (as a portable pump),
- emergency portable booster pump,
- vessel dewatering,
- offshore oil well fires, and
- oil spill cleanup (with a small modification)

References:

1. R.A. Burns, "Firefighting Module Development," NASA Technical Memorandum, NASA TM-82444, October 1981.^(b)

4.4 OAK RIDGE NATIONAL LABORATORY (ORNL)

TECHNOLOGY: Lubricants for Warm Forming of Metals

Applicable Industry; Process Element(s):

Aluminum: 6.0 Fabrication and Milling
Steel: 5.0 Fabrication^(a)

Laboratory: ORNL

Contact: Joseph A. Carpenter, Jr.
Mgr., ECUT Tribology Project
(615) 576-2324

ORNL's tribology project will include development of suitable lubricants for warm forming of metals, beginning in late 1983. Joe Carpenter explained that, in forming many metals of current technological interest (e.g., steels) there is a "warm forming" range (400 to 800°C) at which energy requirements are minimal. Within this range, two opposing forces are balanced: the energy required for deformation that decreases with increasing temperature and the energy required to raise the temperature of the metal. Lubricants for hot and cold forming are available and fairly well understood. Below 400°C, fluid film and solid lubricants, such as graphite and molybdenum disulfide, can be used, and above 800°C various glasses can be used. Lubricants for warm forming, however, are nonexistent and thus little extruding/rolling is done between 400 to 800°C. This work is sponsored by DOE/ECUT.

References:

1. "FY 1983-1989 Project Plan - Tribology (The Science of Friction and Wear)", ORNL, Revision 1, January 14, 1983.^(b)

TECHNOLOGY: Friction and Wear of Ceramics at Elevated Temperature

Applicable Industry; Process Element(s):

Cement: 2.0 Crushing and Grinding
5.0 Final Grinding
Paper/Allied Products: 5.1 Mechanical Pulping
11.0 Power and Chemical Recovery^(a)
Petroleum: 2.0 Drilling and Pumping^(a)
4.0-7.0 Refining (power system)

Laboratory: ORNL

Contact: Joseph A. Carpenter, Jr.
Mgr., ECUT Tribology Project
(615) 576-2324

Three basic wear processes found in tribological systems of advanced heat engines and high-temperature rotating industrial machinery are unidirectional sliding (as in a cam and cam-follower or journal bearing), oscillatory sliding (as in a piston ring on a cylinder wall), and rolling (as in roller and ball bearings). Unidirectional sliding is the simplest to describe with rolling the most difficult, and oscillatory sliding intermediate. ORNL is seeking to understand and model these phenomena for ceramics at high temperatures using a phased approach of initial data gathering and theory development followed by more advanced theory development and verification. Quantitative, experimentally verified, theory or theories to predict current performance limits of ceramics to guide designers of advanced heat engines and high-temperature industrial machinery will result.

Initial experiments were started in late 1982, to measure initial friction coefficients and wear rates and to determine wear mechanisms for dissimilar ceramics. These experiments tested simple, unlubricated, unidirectional pin-on-disk sliding at temperatures up to 700°C. A five-by-five matrix (each of five different pins on five different discs) was described by Mr. Carpenter as consisting of a SiN, a SiC, a toughened and non-toughened alumina, and a partially stabilized zirconia. In 1983 and 1984 unidirectional experimental work will continue and be expanded to include the lubricated case. Modeling and theory development will be run concurrently, and similar initial work will begin for oscillatory sliding (up to 1000°C) and rolling (up to 1400°C). In later years, work on unidirectional sliding will enter advanced stages and fully quantitative theory or theories will be developed; work on oscillatory sliding and rolling will continue following a pattern similar to that taken for unidirectional sliding.

References:

1. "FY 1983-1989 Project Plan - Tribology (The Science of Friction and Wear)", ORNL, Revision 1, January 14, 1983. (b)

TECHNOLOGY: Computer-Accessible System for Retrieval of Tribological Design Data

Applicable Industry; Process Element(s):

Aluminum:	1.0	Mining and Transportation
	2.0	Bauxite Processing
	6.0	Fabrication and Milling
Cement:	1.0	Quarrying and Transportation
	2.0	Crushing and Grinding
	5.0	Final Grinding
Paper/Allied Products:	3.0	Timber Harvesting, Transportation and Storage
	4.0	Debarking and Chipping
	5.2	Mechanical Pulping
	7.0	Coating and Converting
Petroleum:	2.0	Drilling and Recovery
Steel:	4.0	Casting
	5.0	Fabrication
Textiles:	2.0	Yarn Making
	3.0	Fabric Construction ^(a)

Laboratory: ORNL

Contact: Joseph A. Carpenter, Jr.
Mgr., ECUT Tribology Project
(615) 576-2324

ORNL will develop (starting in late FY 1983) a computer-based system for retrieval of tribological design data needed by specific industries. Wide-spread incorporation of state-of-the-art knowledge into contemporary designs is seen as an effective and fast way of obtaining energy savings through tribological advances. Although compilations of current data exist, effectively incorporating such information is a problem. The approach taken is to develop computer software whereby a designer of a specific tribological component or system can easily retrieve from data bases the information most pertinent to his needs. A system is expected to be completed for one industry (probably bearings) by the end of FY 1984. It is expected that such a system should be commercially exploited by FY 1986.

References:

1. "FY 1983-1989 Project Plan - Tribology (The Science of Friction and Wear)", ORNL, Revision 1, January 14, 1983.^(b)

TECHNOLOGY: Lubricating Qualities of the Constituents of
Base Stock Oils

Applicable Industry; Process Element(s):

Aluminum: 1.0 Mining and Transportation
Cement: 1.0 Quarrying and Transportation
Petroleum: 7.0 Chemical Treatment^(a)

Laboratory: ORNL

Contact: Joseph A. Carpenter, Jr.
Mgr., ECUT Tribology Project
(615) 576-2324

The development of better correlations between molecular structures and the lubricating qualities of the constituents of base stock (without additives) oils is one thrust of ORNL's tribology project sponsored by DOE/ECUT. Significant differences in the wear performance and oxidation stabilities were observed among various molecular fractions (long chain saturates, aromatics, and polars) separated from base stock oils. Tests were made using a modified, standard four-ball wear tester and a special oxidation stability testing device. Better informed development of friction wear mitigating systems for future energy conversion and utilization devices can result.

References:

1. "FY 1983-1989 Project Plan - Tribology (The Science of Friction and Wear)", ORNL, Revision 1, January 14, 1983.^(b)

TECHNOLOGY: Neutral Solvents

Applicable Industry; Process Element(s):

Paper/Allied Products: 11.0 Chemical Recovery^(a)
Petroleum: 7.0 Chemical Treatment (treatments/additives to
extend fuel supplies)

Laboratory: ORNL

Contact: Josh Johnson
Chemistry Division
(615) 574-4982

Bacterial fermentation using Clostridia strains of a wide variety of carbohydrate-containing feedstocks produce a mixture of alcohols and ketones, often called neutral solvents that contain primarily 1-butanol, with lesser amounts of acetone, isopropanol, and ethanol. ORNL researchers have investigated the production and applications of neutral solvents.

Josh Johnson explained that butyl and propyl alcohols can be used as cosurfactants, or co-agents, in the micellar flooding process for tertiary oil recovery from existing wells. With the exception of 1-butanol, which is fermentation produced, butyl and propyl alcohol are currently produced by petroleum-based products. Neutral fermentations using waste carbon sources such as wood, paper, and dairy wastes are potentially profitable.

Neutral solvents production has an exciting potential application in extending fuel supplies. The major product of Clostridia fermentations, 1-butanol, has advantages over ethanol for fuel blending, although most attention is placed on ethanol fermentation. Advantages are a higher heating value, improved engine performance, and easier separation of 1-butanol from fermentation broth than ethanol.

Another related use for neutral solvents are as additives to a base fuel such as diesel fuel to produce microemulsion fuels. Microemulsion fuels are clear, low viscosity fuels generally formed by adding a mixture of partially neutralized fatty acid, alcohol, and water to a base fuel. Because of their structure and chemical composition, microemulsion fuels can have combustion products different from those of the base fuel. Micro-emulsion fuels made with n-butanol and a diesel fuel base are substantially more stable and lower in viscosity than are those made with ethanol or methanol, suggesting its use.

References:

1. A.L. Compere, et al., "Chemicals for Enhanced Oil Recovery: Biennial Report for the Period April 1976-March 1981," Draft, BETC/W26-11, ORNL, January 1981, pp. 79-84. (b)
2. A.L. Compere and W.L. Griffith, ORNL, "Evaluation of Substrates for Butanol Production," reprinted from Development in Industrial Microbiology, Vol. 20, 1979, pp. 509-517. (b)
3. J.M. Googin, et al., "Technical Considerations in Choosing Alcohol Fuels for Less Developed Countries," ORNL, n.d. (b)
4. W.L. Griffith, et al., ORNL, "Economic Analysis of Neutral Solvents Production", BETC/OR-23, Chapter 4, 1982. (b)
5. M.K. Strohel, et al., "Economic Evaluation of Neutral Solvents Fermentation Product Separation," ORNL/MIT-30, ORNL, July 1981. (b)

TECHNOLOGY: Separations Chemistry

Applicable Industry; Process Element(s):

Aluminum:	8.0	Pollution Control
Paper/Allied Products:	11.0	Chemical Recovery
	12.0	Pollution Control Systems ^(a)
Petroleum:	9.0	Pollution Control
Steel:	7.0	Pollution Control
Textiles:	6.0	Pollution Control

Laboratory: ORNL

Contact: Josh Johnson
Chemical Division
(615) 574-4982

The technique of impregnating (or filling) carbons with various inorganic (or organic) substances to modify their adsorptive properties is old. It is used extensively to prepare materials for gas masks and respirators with enhanced adsorptive properties. Its use for treatment of aqueous streams, however, has received much less attention. ORNL researchers have examined both the techniques for preparing inorganic-filled carbons and the performance of various filled carbons in removing specific substances in aqueous waste streams.

Examples of fillers investigated include ferrous oxides (hydrous Fe_2O_3 and Fe_3O_4), tin oxide (SnO) and sulfides (ZnS and CdS). AgCl -filled activated carbon for removal of iodide was also investigated. For the case of ZnS filler removing metals from solution, the adsorption reaction can be described by the equation

which, in a sense, is an ion exchange reaction. The reaction proceeds when the starting material (ZnS) is more soluble than the one produced by the exchanging ions in the feed ($\text{M}_{2/z}\text{S}$) and occurs in the solid phase without the starting material (ZnS) first going into solution. Such reactions occurring with natural minerals are limited to the surface of the particles. When adsorbents are especially prepared as microcrystalline or amorphous materials by precipitation and drying, the exchange reactions occur beyond the surface of the particles extending through the bulk of the materials.

The inorganic adsorbents by themselves, however, are difficult to prepare in forms suitable for column operation. By filling activated carbons, the

specific adsorptive properties of the filler can be obtained without negating the adsorptive capacities of the activated carbon and while retaining the hydraulic properties of the activated carbon column.

In other work related to the separation of constituents from waste streams, ORNL investigated, with the International Paper Company, the experimental development and pilot plant operation of dynamically formed reverse osmosis and ultrafiltration membranes for the treatment of paper industry wastes. Potential advantages of dynamically formed membranes are the ability to operate at process temperature, relatively high fluxes, and field regeneration of fouled membranes.

Dynamic membranes were formed on porous supports typically having pores in the submicron range. (Dynamic membranes are formed by circulating a suspension of a suitable substance over a porous support under pressure, coating the porous support to form a membrane layer having a porosity less than that of the support material.) In pilot plant tests at International Paper Company, a hydrous zirconium (IV) oxide-polyacrylic acid membrane was used in the reverse osmosis mode to treat pulp mill decker filtrate and a hydrous zirconium (IV) oxide-silicon (IV) oxide membrane was used in the ultrafiltration mode to treat bleach plant caustic extract filtrate.

During the pilot plant operation, the reverse osmosis unit treated the decker filtrate to a reusable quality, and the ultrafiltration unit was able to concentrate the bleach plant waste water to a solids concentration of greater than 10 percent. Both units achieved better than 98 percent color removal and high levels of organic compound removal. The ultrafiltration unit was capable of fluxes of $4.07 \text{ m}^3/\text{m}^2/\text{d}$ or higher, and the reverse osmosis unit produced fluxes in excess of $1.63 \text{ m}^3/\text{m}^2/\text{d}$.

Reference:

1. L.J. Breithaupt and J.S. Johnson, "Hyperfiltration and Ultrafiltration of Kraft Pulp-Mill and Bleach Plant Wastes," for seminar: Membrane Separation Technology, Clemson University, August 1977. (b)
2. P.C. Ho and K.A. Kraus, ORNL "Adsorption on Inorganic Materials - VIII: Adsorption of Iodide on AgCl-Filled Carbons," J. Inorganic Nuc. Chem., Vol 43, 1980, pp. 583-587. (b)

3. K.A. Kraus and J.S. Gilbert, "Activated Carbons Filled with ZnS as Adsorbents," Proc. 31st Purdue Industrial Waste Conference (Ann Arbor, Mi: Ann Arbor Science, 1977), pp. 1046-1058. (b)
4. J.T. McKinnon "Advanced Filtration of Pulp Mill Wastes," EPA-600/2-79-209, 1979. (b)
5. F. Nelson, et al., ORNL, "Adsorption of Inorganic Materials on Activated Carbon," Proc. 29th Purdue Industrial Wastes Conference (Ann Arbor, Mi: Ann Arbor Science, 1974), pp. 1076-1090. (b)

TECHNOLOGY: Industrial Insulation, Refractories, and Recuperation

Applicable Industry; Process Element(s):

Aluminum:	4.0	Smelting
	5.0	Alloying
Cement:	3.0	Pyroprocessing
Petroleum:	5.0	Separation
	6.0	Conversion
Steel:	1.0	Agglomeration
	2.0	Smelting
	3.0	Steel Making (a)
	4.0	Casting
	5.0	Fabrication
	8.0	Coke Making

Laboratory: ORNL

Contact: T. Schaffhauser, Manager
Conservation Technology Programs
(615) 574-4826

Tony Schaffhauser reviewed ORNL's considerable expertise in industrial insulation and refractories and stated that the lab has the capabilities and willingness to work with industry on technical problems. An excellent refractory and insulation test facility (also a recuperator test facility) is available to industry.

Current insulation research takes direction from a comprehensive assessment of industrial thermal insulation prepared in 1976. Examples of insulation research include the study of radiation leakage in styrofoam or urethane insulation. Coal dust added to urethane reduces radiative leakage; freon blown urethane is an improvement over air blown with a half life of 50 years. Effects of alternative fuels on furnace refractories and insulation as from high vanadium crudes from Venezuela and high zinc crudes from Kentucky were examined at

ORNL's test facility. Test facility has the capability to burn oils and coal/oil mixtures, but not coal.

To assess potential use of ceramics in heat exchangers, the corrosion behavior of SiC and Al₂O₃ tubes in fossil fuel combustion environments have been studied by ORNL.

In related work, recent recuperator tests with GTE/Sylvania ceramic matrix recuperator with #6 oil as the furnace fuel showed plugging from combustion ash and interaction of the cordierite ceramic core (MAS) with fuel impurities. No problems were encountered when using low-sulfur distillate. Carborundum is currently testing carbide tubes at the facility.

References:

1. R.G. Donnelly, et al., "Industrial Thermal Insulation - An Assessment," TID-27120, prepared by ORNL for ERDA, August 1976. (Available from NTIS.)^(b)
2. "FY 1983-1989 Project Plan-Materials," ORNL, Revision 1, November 1982.^(b)

TECHNOLOGY: Coatings for Corrosion/Erosion Resistance

Applicable Industry; Process Element(s):

Aluminum:	1.0	Mining and Transportation
	2.1	Crushing
	2.4	Pulverizing
	3.0	Alumina Refining (abrasive resistant values)
	6.0	Fabrication and Milling
Cement:	1.0	Quarrying and Transportation
	2.0	Crushing and Grinding
	5.0	Final Grinding
Paper:	3.1	Harvesting
	4.0	Debarking and Chipping/Grinding
	5.1	Mechanical Pulping
Petroleum:	2.0	Drilling and Pumping ^(a)
Steel:	5.0	Fabrication
Textiles:	1.0-4.0	Fiber and Fabric Production (erosion resistant coatings for cutting blades and erosion prone surfaces)

Laboratory: ORNL

Contact: Jack Lackey or Arnie Olsen
Metals and Ceramics Division
(615) 574-4551

An interesting procedure for chemical vapor deposition (CVD) of titanium diboride (TiB_2) was described by Jack Lakey to obtain a wear resistant surface for metal cutting/abrad-ing, valves for slurries, and, in general, wherever cemented carbides are now used. Performance has been better than cemented tungsten carbide. Formation of composites is also possible as in chemical deposition on a ceramic fiber matrix to obtain a tough ceramic composite.

Plasma and laser activated processes for coating are also practiced. In plasma activation, gases are heated for higher deposition rates without heating the substrate, some of which could not withstand deposition temperatures.

TECHNOLOGY: Amorphous Metals

Applicable Industry; Process Element(s):

Aluminum:	2.1	Crushing
	2.4	Pulverizing
Cement:	1.1	Quarrying
	2.0	Crushing and Grinding
	5.0	Final Grinding
Paper:	3.1	Harvesting
	4.0	Debarking and Chipping/Grinding
	5.0	Pulping and Bleaching
	6.0	Paper and Paperboard Production
	11.0	Power and Chemical Recovery ^(a)
Petroleum:	2.1	Drilling
	5.0	Separation
	6.0	Conversion
Steel:	5.0	Fabrication
Textiles:	1.0-4.0	Fiber and Fabric Production (erosion resistant cutting blades and surfaces)

Laboratory: ORNL

Contact: Carl Koch
Metals and Ceramics Division
(615) 574-5156

A focus of research on amorphous metals at ORNL has been on improved materials, the ferro-magnetics, for electric motors and core materials for transformers. These, however, retain amorphous character only to 300 to 400°C. Annealing has led to embrittlement problems. Work with zirconium nickel, which has a wide range of mixes over which it can be made amorphous, and tantalum

iridium (for superconductors) is also being done; these retain amorphous character in the 1000°C range. Further, amorphous metal is being laid down by vapor deposition as well as liquid. A tube substrate, for example, could be coated either inside or outside, which, along with high temperature capability, provides an exciting potential for use in corrosive atmospheres.

TECHNOLOGY: Long Ranged Ordered (LRO) and Ordered Intermetallic Alloys
for High Temperature Structural Applications

Applicable Industry; Process Element(s):

Aluminum:	5.0	Alloying
Paper:	11.0	Power and Chemical Recovery
Petroleum:	5.0	Separation
Conversion:	6.0	Conversion
Steel:	4.0	Casting
	5.0	Fabrication ^(a)

Laboratory: ORNL

Contact: V.J. Tennery, Director
High Temperature Materials Laboratory Nuclear Division
(615) 574-5123

ORNL is engaged in investigations of the engineering properties of advanced materials with potential application in high-temperature structural applications such as in heat engines and steam turbines. Vic Tennery explained that metallic alloys with ordered crystal structures and having sufficient ductility are possible substitutes for austenitic stainless steels and superalloys without the use of costly strategic materials (e.g., Cr, Co) found in these currently used heat resistant materials.

Nickel and iron aluminides, belonging to a class of materials known as intermetallics, are strong, stable, and corrosion and oxidation resistant at high temperatures. Their use as structural materials, however, is limited by their brittle fracture and low ductility. ORNL researchers examined a microalloying approach to lessen the problems of grain boundary embrittlement of Ni_3Al . (Weak grain boundaries cause brittle intergranular fracture without much plastic deformation of the grains in polycrystalline forms of Ni_3Al .) Among the dopants added (Ce and Mn, and B) boron (at a few hundred ppm levels) was found to be most effective in improving fabricability and ductility of Ni_3Al . The B-doped Ni_3Al alloys had the unique and desirable combination

of high temperature strength, oxidation resistance, and adequate ductility and fabricability.

In addition, Mr. Tennery discussed long range ordered (LRO) alloys, a unique class of materials that form ordered crystal structure at a temperature below the critical ordering temperature (T_c). LRO alloy work at ORNL, based on $(\text{FeNi})_3\text{V}$, is aimed at improving high-temperature properties and reducing costs. New alloys were prepared from the basic $(\text{FeNi})_3\text{V}$ composition by varying the iron to nickel ratio and partial replacement of vanadium with titanium and aluminum. Tensile properties (modulus, yield, and ultimate) creep and fatigue resistances, crack-growth behavior, and hydrogen permeabilities were measured. One alloy, Fe-40% Ni-23% V modified with a small amount of niobium, investigated for steam turbine applications, had a creep rate at 670°C , four orders of magnitude lower than type 316 stainless steel. T_c , the temperature at which material undergoes the order-disorder transformation for the alloy with the general formula $(\text{Fe}_{30}\text{Ni}_{70})_3(\text{V}_{90-x}\text{Ti}_2\text{Al}_x)$, being investigated for advanced heat engine applications, increases from 800 to 1000°C as x varies from 0 to 30.

References:

1. C.T. Liu and C.C. Koch, "Development of Ductile Polycrystalline Ni_3Al for High Temperature Applications." ORNL, n.d.(b)
2. "FY 1983-1989 Project Plan-Materials", ORNL, Revision 1, November 1982.

TECHNOLOGY: Structural Ceramics

Applicable Industry; Process Element(s):

Aluminum:	4.0	Smelting
	5.0	Alloying
Cement:	1.1	Quarrying
	2.0	Crushing and Grinding
	5.0	Final Grinding
Paper:	3.1	Harvesting
	4.0	Debarking and Chipping/Grinding
	5.1	Mechanical Pulping
	11.0	Power and Chemical Recovery
Petroleum:	2.0	Drilling and Pumping
	5.0	Separation
	6.0	Conversion
Steel:	4.0	Casting
	5.0	Fabrication ^(a)

Laboratory: ORNL
Contact: V.J. Tennery, Director
High-Temperature Materials Laboratory
Nuclear Division
(615) 574-5123

High-temperature resistance and high mechanical strength make ceramics (e.g., SiC, SiN₄, TiB₂) promising candidates for structural materials in many applications, including applications where only metals were considered previously, e.g., cutting tools. Brittleness is a disadvantage of ceramics in structural applications; fabrication and attachment of ceramic materials are additional problem areas.

TiB₂ has several valuable properties, including high melting temperature, high electrical conductivity and non-reactivity with various liquid metals; potential applications are as cutting tools, valve trim for erosive environments and as cathodes in Hall-Heroult cells for aluminum smelting. Fabrication into various shapes required for such applications requires high-density polycrystalline ceramic bodies. Densification of TiB₂ necessitates high (2000°C) sintering temperatures which is costly and requires special equipment. Also, TiB₂ exhibits thermal expansion anisotropy, producing internal stress during cooling and generating microcracking when grain size is about a critical value. Microcracking, which occurs in grains and at grain boundaries, results in degradation of macroscopic mechanical properties. A technique was demonstrated at ORNL whereby TiB₂ powders were sintered to near theoretical densities using modest hot pressing procedures when prescribed diboride particles are used in conjunction with liquid sintering activation agents based on metals such as Ni. The grain growth and microcracking characteristics of typical TiB₂ ceramics was avoided. Evaluation as cutting tools showed performance comparable with WC-Co based tools under identical metal-cutting conditions. B&W is involved in experiments with TiB₂ as a cutting tool material.

Under sponsorship of DOE/ECUT, ORNL is exploring technologies for joining ceramics that have potential application in advanced heat engines and high-temperature heat exchangers. Development of predictive models for typical attachments and concurrent experimental testing of model predictions will enable increased understanding of problems and limitations in such joining.

Development of reactive metal brazes for joining SiC to SiC and partially stabilized zirconia (PSZ) to ductile iron, specifically brazes based on Ni-Cr-Ti for joining SiC to SiC and Ti-Cu-Be and Ti-Zr-Be for joining PSZ to ductile iron, has been initiated. Much of the work on joining PSZ to ductile iron was done in conjunction with the Cummins Engine Company in their efforts in development of the adiabatic diesel concept. Screening of developmental brazes on the basis of their wettability of ceramics and metals using levitation melting and sessile drop test apparatus was done and will continue. Exploration of advanced joining techniques for "new" high technology ceramics (e.g., metal dispersion-transformation-, and fiber-toughened forms) will be initiated in the future as will examination of techniques for non-destructive investigations of ceramic attachments.

ORNL is also active in several other areas of ceramics research. For example, ORNL has evaluated the corrosion behavior of selected ceramics (e.g., SiC and Al_2O_3 tubes) in fossil fuel combustion environments. Results were used to assess potential use of the ceramics in heat exchangers. Additionally, in cooperation with Air Products, ORNL is examining sol gel processing/chemical synthesis applied to SiC manufacture. (The procedure avoids abraiding, attendant ball milling and the contaminants inherent thereto.) Finally, ion-implantation work (for both metals and ceramics) is underway to reduce friction and increase toughness. For example, ion-implantation of Cr ion SiC creates an amorphous-like slippery surface. It also toughens ceramics by making a ductile skin over a non-ductile substrate. An ion-implantation user's facility exists.

References:

1. V.J. Tennery, et al., ORNL, "Structure-Property Correlations for TiB_2 -Based Ceramics Densified Using Active Liquid Metals," presented at International Conference on the Science of Hard Materials, Moran, WY, August 1981. (b)
2. "FY 1983-1989 Project Plan - Materials," ORNL, Revision 1, November 1, 1982. (b)

TECHNOLOGY: Sensors

Applicable Industry; Process Element(s):

- Aluminum: 2.0 Bauxite Processing (crushing, pulverizing, kiln operation)
- 3.0 Alumina Refinery

Cement:	2.0	Crushing and Grinding (noise analysis)
	3.0	Pyroprocessing (telemetry system) ^(a)
	5.0	Final Grinding (noise analysis)
Paper:	4.0	Debarking and Chipping/Grinding (noise analysis)
	5.0	Pulping and Bleaching
	11.0	Power and Chemical Recovery
Petroleum:	2.0	Drilling and Pumping
Steel:	6.0	Process Controls
Textiles:	2.0	Yarn Making
	3.0	Fabric Construction
	4.0	Fabric Finishing

Laboratory: ORNL

Contact: Norm Bradley
Instrumentation and Controls Division
(615) 574-5701

ORNL has a wealth of experience and capabilities in the development and use of advanced sensors, much of it related to work in nuclear reactors, nuclear fuel processing, and fossil energy. ORNL maintains an instrumentation and control facility. Examples of advanced sensor and control work include:

- High-temperature thermocouples and reactor grade thermocouples (primarily for nuclear reactors). The ORNL Instrument Division has been a center of excellence in high-temperature measurement for many years.
- Optical pyrometers.
- Telemetry system for transmitting temperature profiles from nuclear fuels processing (rotary) kiln. Cement industry and pulp and paper industry (lime kiln) can potentially benefit.
- Low-cost, cross-correlation device for measurement of turbulent flow.
- Ultrasonic flow sensors.
- Torsional ultrasonic level meter (measures fluid level, density, and temperature). Potentially useful for shipbuilders and others.
- Low-flow calibration system for liquids flow sensing.
- Infra-red and microwave moisture sensing capability.
- Equipment that quantifies small particles in low concentration in liquids.
- On-line spectrophotometric capability for measuring uranium salt concentration. Potential for measurement of unreacted alkalis and other industrial process fluid constituents (e.g., dyes).
- Trouble shooting capability via noise analysis of rotating equipment. Control of comminution/grinding equipment may be applicable.

In more material-related sensor work, ORNL researchers under the Advanced Instrumentation for Reflood Studies (AIRS) Program developed and supplied instrumentation systems for measurement of three dimensional, two-phase (steam

and water) flow parameters in non-nuclear reflood test facilities to study such three dimensional phenomena in the upper plenum and core of a pressurized water reactor during the reflood stage of a loss of coolant accident. Instrumentation work included the development of a guide tube impedance probe, a device in which the electrical impedance between two electrodes extending into the sub-channel spacing between three fuel rod simulators is measured to provide information on the local ratio of steam and water. By cross correlation of the electrical output of two axially separated sensors, flow velocity and direction can be determined. Conditions in the reactors during the reflood stage of a loss of coolant accident cause severe thermal shock to sensor components (an estimated temperature drop of 300°C/s) necessitating the use of specialized materials.

A key to the sensor was the development of an impermeable, thermal shock-resistant electrically insulating alumina cermet that contains 0.5 to 1.5 volume % finely dispersed platinum or chromium. The cermets are produced by hot pressing Al_2O_3 -Pt or Al_2O_3 -Cr powders containing finely dispersed metal particles obtained by in-situ reduction of platinum chloride or chromium nitrate. The metal particles increase the thermal-shock resistance by impeding and diverting cracks and by mechanically locking ceramic grains. The ceramic-to-metal seal system for the sensor consists of the cermet directly brazed to one or more metallic transition pieces with a brazing filler material. Transition pieces, made of platinum or platinum and type 446 ferritic stainless steel, were necessary to accommodate the thermal expansion coefficients of the insulator and the stainless steel sensor housings or sheath of electric cables. The brazing filler material, developed at ORNL, has a composition of 49 Ti-49 Cu-Zr Be (wt. %).

References:

1. A.W. Dearbrocik, "State-of-the-Art Assessment of Coal Preparation Plant Automation," ORNL 5699.
2. A.J. Moorhead, et al., ORNL, "Brazing of Sensors for High Temperature Steam Instrumentation Systems," reprinted from Welding Journal, April 1981, pp. 18 to 28.^(b)
3. C.S. Morgan, et al., "Thermal-Shock Resistant Alumina-Metal Cermet Insulators," American Ceramic Society Bulletin, Vol. 61, No. 9, September 1982, pp. 974-981.

4.5 BROOKHAVEN NATIONAL LABORATORY (BNL)

TECHNOLOGY: Corrosion Research Capabilities

Applicable Industry; Process Element(s):

Aluminum:	5.0	Alloying
Paper:	11.0	Power and Chemical Recovery ^(a)
Petroleum:	4.0	Washing
	5.0	Separation
	6.0	Conversion
Steel:	5.0	Fabrication

Laboratory: BNL

Contact: John R. Weeks
Head, Materials Technology Div.
(516) 282-2617

The corrosion research capabilities of Brookhaven National Laboratory (BNL) are divided between the Department of Applied Science (DAS) and the Department of Nuclear Energy (DNE), with the majority of current work being performed by personnel of the DNE Materials Technology Division.

The equipment for performing corrosion research is concentrated in DNE; however, various facilities throughout the laboratory, including the National Synchrotron Light Source (NSLS), and several facilities within the Physics Department and DAS for examining the nature of surface films on metals are also available to the corrosion scientists.

Current research programs in the corrosion area range from fundamental research funded by DOE, Division of Basic Energy Sciences, to applied experimental research funded by the DOE, Division of Geothermal Energy, the NRC's Division of Reactor Safety Research, the Army Research Office, and the Electric Power Research Institute. Technical assistance programs are also being performed for the NRC on corrosion experiences throughout the LWR nuclear industry, and on waste storage canisters. Phenomena studied range from low temperature, localized or pitting types of corrosion, to high temperature corrosion and stress corrosion cracking that have occurred on various stainless steels and Inconel alloys as well as turbine materials.

The current research interests of the group are predominantly in high temperature water, including geothermal streams or brines, nuclear primary or secondary coolants. The overall goal is developing a basic understanding of corrosion phenomena occurring at these high temperatures. In addition, however, there has been considerable work related to localized corrosion and stress corrosion phenomena occurring at ambient temperature and pressures, and to developing techniques for remote monitoring of corrosion processes, at both ambient and high temperatures and pressures.

Special research techniques for studying these phenomena have been developed at BNL, including scanning reference electrode techniques to permit detailed study of localized corrosion as a function of time and location on a material, and more recently, a scanning AC reference electrode tool that is again ideal for studying the onset of localized corrosion on a surface. Both of these apparatus are equipped with computer data analysis systems as well as sophisticated electronic controls to permit precise study of the electrochemical processes involved in the localized corrosion.

BNL also has the capabilities and research interests for studying the behavior of hydrogen in metals, including both electrochemical and mechanical effects on the materials. The effects of environment on the behavior of both organic and inorganic coatings on materials are being studied, as well as developing methods for detecting flaws in these coatings. Considerable research has also been performed on the effects of localized corrosion in the area of welds and defects in surface coatings. Acoustic emission equipment is being used to develop an improved understanding of stress corrosion cracking mechanisms.

TECHNOLOGY: Kinetics and Mechanisms of Alternative Fuels Combustion

Applicable Industry; Process Element(s):

Aluminum:	8.0	Pollution Control (also Power Systems)
Cement:	7.0	Pollution Control (also Power Systems)
Paper:	11.0	Power and Chemical Recovery
	12.0	Pollution Control
Petroleum:	9.0	Pollution Control (also Power Systems) ^(a)

Steel: 7.0 Pollution Control (also Power Systems)^(a)
Textiles: 6.0 Pollution Control (also Power Systems)

Laboratory: BNL

Contact: R.B. Klemm or J.V. Michael
Department of Applied Science
(516) 282-3819

In work sponsored by DDE, Division of Basic Energy Sciences, BNL researchers are seeking to produce absolute rate data for elementary combustion-related reactions, and to investigate the mechanistic factors involved in gas phase combustion and pollutant formation processes. Particular emphasis is placed on alternative fuels that comprise a wide range of fuel types, including methyl and ethyl alcohol, hydrocarbon synfuels, and hydrogen. There is an additional long range and fundamental interest in the effects of combustor operating conditions and fuel parameters on the mechanisms of combustion, such as pollutant emission rates and combustion efficiency.

The complementary techniques of discharge flow and flash photolysis are used in determining specific rates for combustion-related, elementary atom-molecule reactions. Combined, these experimental methods provide an unusually wide temperature span, about 200 to 1200K, over which direct kinetic studies may be made for a wide range of combustion initiation reactions and oxidation reactions of combustion intermediates. This temperature range will be extended to a considerable extent, up to about 2500K, by a shock tube experiment that is being completed during the current fiscal period (FY 83). In addition, a photoionization mass spectrometer (PIMS) experiment that uses the National Synchrotron Light Source facility has been developed jointly between BNL's Departments of Energy and Environment and Chemistry. The PIMS apparatus is employed in this task to determine reaction branching ratios by identifying primary reaction products that are sampled via a molecular beam from a discharge flow tube.

References:

1. J.V. Michael, D.G. Keil, and R.B. Klemm, "A Resonance Fluorescence Study of Oxygen Atom + Hydrocarbon Reactions. V: $O(^3P) + \text{Neopentane}$ (415-922K)," BNL 31559, Proc. 19th Symposium (Intern.) on Combustion, The Combustion Institute, Pittsburgh, in press.^(a)

2. G.M. Provencher, T. Tanzawa, D.G. Kiel and R.B. Klemm, "Absolute Rate Parameters for the Reaction of $O(^3P)$ with Iso-butane (abstract)," BNL 31560, presented at the 7th Intern. Gas Kinetics Symposium, Gottingen, West Germany, August 1982.^(b)

TECHNOLOGY: Calcium Silicate Cement Sorbent for H_2S Removal and Improved Coal Gasification Processes

Applicable Industry; Process Element(s):

Cement: 6.0 Process Control (product development)^(a)
Petroleum: 9.0 Health, Safety and Pollution Control

Laboratory: BNL

Contact: H.J. Yoo
Department of Applied Science
(516) 282-3819

Limestone, when used as a sorbent for desulfurizing combustion gases in fluidized-bed combustors, has several drawbacks. Its sorption capability decreases markedly above $850^{\circ}C$; it cannot be easily regenerated economically (even at a temperature of $1000^{\circ}C$); it has serious attrition loss problems in fluidized bed reactors; its reactivity is highly variable depending on the type of natural limestone. Because use of limestone is possible only on a "once-through" basis, commercialization of fluidized bed systems could be hampered because vast amounts of spent sorbent will be generated. Therefore, the need exists to find alternative, regenerative sorbents for FBC application.

At BNL's Process Sciences Division, commercially available calcium silicates in the form of Portland Cement III (PC III) Agglomerated Cement Sorbent pellet (ACS) and related sorbents are being evaluated for in situ high temperature removal of H_2S and COS in low and medium Btu coal fluidized-bed gasifiers. PC III promises to be highly efficient at high operating temperatures of the gasifiers in contrast to limestone and iron oxide which suffer from lower operating temperature limitations. ACS pellets have indicated an improved gasification efficiency in low Btu, FBG coal gasifiers. Sorbent capacities and kinetics of removal for H_2S and COS will be determined initially in thermogravimetric analyzer (TGA) experiments at temperatures up to $1250^{\circ}C$ ($2300^{\circ}F$) and at pressures from 1 to 20 atm. The sorption rate, regeneration rate, capacity, and attrition of sorbents will be determined in

bench-scale fluidized-bed experiments using simulated gasifier mixtures. The sorbent regeneration efficiency and rate will be determined in TGA and fluidized-bed experiments. Sorbent performance will be compared to limestone and dolomite. The catalytic effect of the sorbents on the gasification of coal will be investigated. The results of this basic long-term research has high payoff for application by an industrial organization demonstrating the chemically active fluidized system. Tests of the cement sorbent will be performed in a larger coal-fired, bench-scale FBG, and this is being performed in conjunction with an industrial collaborator, the Foster-Wheeler Corporation.

References:

1. H.J. Yoo, P.J. McGauley and M. Steinberg, "Calcium Silicate Cements for Desulfurization of Combustion Gases," Semi-annual Progress Report, April 1-September 30, 1981, BNL 51519, February 1982. (b)
2. H.J. Yoo, P.J. McGauley and M. Steinberg, "Calcium Silicate Cements for Desulfurization of Combustion Gases." BNL 31083, presented at 184th National ACS Mtg. Kansas City, MO, September 1982. (b)

TECHNOLOGY: Research and Implementation of Concrete-Polymer Overlays and Patching Material

Applicable Industry; Process Element(s):

Cement: 6.0 Process Control (product development)

Laboratory: BNL

Contact: J.J. Fontana
Department of Applied Science
(516) 282-3819

Deterioration of Portland cement concrete bridge decks and other structures is generally caused by chloride-induced corrosion of the reinforcing steel which results in cracking and spalling of the concrete because of the volumetric increase of the corroded steel. Although this deterioration can be prevented in new structures by the use of epoxy-coated reinforcing steel, there are thousands of salt-contaminated structures that are structurally sound but in which corrosion is active. The high maintenance costs, the public inconvenience, and the safety hazards associated with concrete repairs have resulted

in a concerted effort by FHWA to develop durable, rapid-curing patching materials and impermeable, skid-resistant overlay systems.

Under contract to FHWA, BNL has developed a polymer-concrete (PC) patching material that combines the premix characteristics of Portland cement concrete (PCC) with strength and durability properties exceeding those of PCC. The same material has been used for thin overlays to restore skid resistance to PCC polished decks and to provide a wear resistance surface.

An automated resin spray system was built and tested at BNL. This equipment is to be used for the placement of thin sand-filled resin overlays. The spray system and sand spreading equipment was used by FHWA to place an overlay in Virginia. The equipment functioned properly and is now under their jurisdiction.

Corrosion-prone structures can be protected by the use of impressed current cathodic protection techniques which drive off the chloride ions and passivate the steel. Needed for such a system is an economical and durable electrically conductive overlay material. BNL researchers have shown that, by incorporating coke breeze into the first two layers of the thin sand-filled resin overlays, they can be made electrically conductive. Evaluations with respect to the resistivity and durability of the overlay are presently being made.

It also appears that a premixed polymer concrete overlay can be made electrically conductive by incorporating coke breeze in the mixture. This electrically conductive polymer concrete appears to meet the requirements of FHWA and is also being evaluated.

References:

1. J.J. Fontana and J. Bartholomew, "Polymer Concrete Patching Manual," BNL 30364, November 1981.
2. J.J. Fontana and W. Reams, "Repairs with Polymer Concrete," BNL 31146, December 1981.
3. D.W. Huszagh, "Pneumatically Controlled Resin Spray Machine for Polymer Concrete Overlays," BNL 31767, April 1982.

TECHNOLOGY: Water-Compatible Polymer-Concrete Materials

Applicable Industry; Process Element(s):

Cement: 6.0 Process Control (product development)

Laboratory: BNL

Contact: T. Sugama
Process Sciences Division
(516) 282-3019

The U.S. Air Force is currently engaged in a program to develop methods for rapidly repairing bomb damaged concrete runways. Because of its high strength and rapid cure, polymer-concrete (PC) is one of the most promising repair materials. For PC to be a significantly faster repair method than more conventional techniques, curing times of less than 1 hr. are necessary. Durability and high strength are also needed. Probably the most difficult requirement for the material is rapid placement under all weather conditions. The materials must be usable over a wide range of temperature and under all forms of precipitation. This unique feature of all-weather repairs is what separates the rapid runway repair requirements from conventional highway and airport routine repair.

In support of the above program, BNL is developing water-compatible inorganic and organic-based cements. The specific goal of the work is to develop at least one formulation that has the following characteristics: compressive strength greater than 2000 psi at an age of 1 hr., flexure strength greater than 400 psi, bond strength greater than 100 psi, non-toxic, non-flammable, long storage life, and low cost. The storage temperature for materials ranges from -15° to 43°C and the temperature during placement and curing is from -32° to 52°C . To date, the results from laboratory and field tests performed in conjunction with the USAF, indicate that most of these criteria can be met by the use of a furfuryl alcohol PC (FA-PC) and a magnesium polyphosphate cement. Work on both systems will be continued in FY 1983.

Research on magnesium monophosphate cement indicated potential application as construction materials and surface coatings for fire proofing structural elements in addition to use in rapid repair systems.

References:

1. T. Sugama and L.E. Kukacka, "Effect of Zinc-Levulinic Acid and Chelate Compounds Formed in Furfuryl Alcohol Polymer Concrete," BNL 29787R, June 1981.^(b)
2. T. Sugama and L.E. Kukacka, "Products Formed in Aged Ca-Polyester Complexed Polymer Concrete Containing Cement Paste", BNL 31172, March 1982.^(b)
3. T. Sugama and L.E. Kukacka, "Magnesium Monophosphate Cements Derived from Diammonium Phosphate Solutions," BNL 31659, Cement and Concrete Res., in press.^(b)

TECHNOLOGY: Geothermal Materials Development: Geothermal Well Cements

Applicable Industry; Process Element(s):

Cement: 6.0 Process Control (product development)
Petroleum: 2.1 Drilling^(a)

Laboratory: BNL

Contact:	L.E. Kukacka	or	D. van Rooyen
	Department of Applied Science		Department of Nuclear Energy
	(516) 282-3819		(516) 282-3814

The lack of durable cost-effective materials of construction is a serious problem in the development of geothermal resources for electric power generation and direct utilization. Some materials that withstand the geothermal environments exist, but they are too expensive to be cost-effective or the market is too small or uncertain for the private sector to invest in new materials development. Specific needs include high temperature sealing materials for use in well logging equipment, pumps, drill bits, packers, and blow-out preventors. Durable materials for drill bits, casings, well cements, pump and drill bearings, process components, equipment foundations, and cooling towers are also needed.

BNL, in support of DOE's Geothermal and Hydropower Technologies Division, performs both technical and managerial duties in the area of high-risk/high-payoff geothermal materials research and development. An example is a comprehensive program to develop and test geothermal well cementing materials. The methods and materials used in geothermal wells are similar to those used in oil and gas wells, although they must withstand more severe conditions such as well

temperatures as high as 370°C and extremely saline and corrosive formation brines.

The design criteria for the geothermal cementing materials development are:

S_c (compressive strength)	= 6.9 Nm^{-2} at 24 h
K (permeability to water)	= 1.013 kNm^2
S_b (bond strength between cement and steel casing)	= 69 kNm^{-2}
D (thermal and chemical stability)	= No significant reduction in strength or permeability after prolonged exposures at 400°C to 25% brine solutions, flashing brine or dry steam.
T_p (pumping time)	= 3 to 4 hr. at expected placement temperature.

Compatibility of the cement with drilling mud.

Noncorrosive to steel well casing.

Twenty-seven cements identified in an R&D phase of the program or supplied by industry have been evaluated in the laboratory. Sixteen of these materials were selected for downhole investigations; data for 3 month exposures to flowing brine at 210°C are available. Further evaluations are planned after 6 and 12 month exposures, and depending on these results, tests will be initiated at 350°C.

Several cements with excellent properties have been identified. A significant observation from laboratory investigations is that Portland cements of normal weight, similar to those already in use at most geothermal areas, have shown little deterioration after exposure to 20 percent brine at 300°C and 20 Nm^{-2} pressure for 28 days. Also, promising lightweight systems based on modifications to Portland cement have been identified; these will be important in reducing formation damage and lost circulation problems. In the downhole tests, specimens cured downhole and exposed to sandstone cores yielded better properties than pre-cured cubes that were exposed directly to the flowing

brine. The former situation is believed a more accurate reflection of downhole service conditions where the cement is behind a steel well casing. The highest strengths (greater than 90 Mnm^{-2}) and lowest permeabilities (less than 0.01 Nm^2) were obtained with formulations of a class J cement and an organo-siloxane polymer cement. A lightweight slurry (density of 1.55 kg l^{-1}) has yielded a cement that appears durable. Results obtained thus far should be reassuring to those using such slurries. Because most of the cements were formulated for use at temperatures of less than 7300°C , it is expected that significant property improvements may be observed as downhole temperature is increased.

Reference:

1. L.E. Kukacka, "Concrete-Polymer Composites; Current Status and Future Research Needs," BNL 29501, Proc. of International Symposium on Plastics in Material and Structural Engineering, Prague, Czechoslovakia, June 23-25, 1981.^(b)
2. L.E. Kukacka, "Geothermal Well Cement, Current Status of R&D and Downhole Testing," BNL 30348, Proc. of International Conference on Geothermal Energy, Florence, Italy, May 11-14, 1982.^(b)

4.6 IDAHO NATIONAL ENGINEERING LABORATORY (INEL)

TECHNOLOGY: The Determination and Identification of Microbial
Production of Inducible Metallothionein-Protein

Applicable Industry; Process Element(s):

Aluminum:	8.0	Pollution Control (metal recovery from waste streams, wastewater treatment)
Petroleum:	4.0	Washing ^(a)
	9.0	Pollution Control (metal recovery from waste streams, pollution control)
Steel:	7.0	Pollution Control (metal recovery from waste streams, wastewater treatment)
Textiles:	6.0	Pollution Control (removal of metal based dyes from waste streams)
Other Application Areas:		Mineral Recovery from Mine Washings Mineral Recovery from Sea Water

Laboratory: INEL

Contact: Dr. J.H. Wolfram
(208) 526-8135

This project, supported by the U.S. Bureau of Mines, is aimed at enhancing the tendencies of certain microorganisms for selective sorption of valuable elements from dilute solutions such as waste streams, mine waters, etc.

The washing of oil from enhanced recovery was selected as the most applicable taxonomy element because a relatively high percentage of petroleum crudes recovered from the two-thirds "still in the hole" via EOR techniques contain considerable metallics that not only have to be removed, they are also a weight problem in transport to the refinery. Consequently, if microorganisms could be used, via the biocatalysis of their enzymes or any other mechanism including metallic absorption, to separate these metallics it might prove beneficial to the refining of crude oil.

The extraction of minerals from sea water has been a goal of mankind for a very long time but usually gets defeated by the extreme dilution of the sea water. However, if a microbe could be identified that could separate desirable metallics in highly dilute suspensions, it might be worth the examination of a metals/mining operation. Since microbes only seem to survive in very dilute systems, the dilute nature of minerals in sea water may be helpful.

TECHNOLOGY: Joining of Silicon Nitride Based Ceramics

Applicable Industry; Process Element(s):

Aluminum:	5.0	Alloying
Cement:	4.0	Clinker Cooling
Petroleum:	6.1	Thermal Cracking
Steel:	3.0	Steel Making
	5.0	Fabrication ^(a)

Laboratory: INEL

Contact: Dr. P. Kelsey
(208) 526-8328

This project, supported by the U.S. Bureau of Mines, is aimed at developing the fundamental technology of joining Si_3N_4 ceramics. This work addresses one of the major shortcomings of current ceramics. This is that virtually every single fluid heat exchanger application of ceramics, which the four above are, must have a joint or joints somewhere in the assembly. The fundamental problem of joining one ceramic piece to another is made worse for a heat exchanger because each pass of the heat exchanger through the fluid needs two joints and, to be effective, a heat exchanger must have many passes and correspondingly many joints. In all of the preceding taxonomy applications, ceramic heat exchangers would be excellent because of their resistance to high temperature erosion and corrosion.

In the use of ceramics for gas turbines, one of the more serious problems is the interface between the ceramic and the metal which is frequently done with variable success by using a coating on the metal that is graded in properties, being more metallic near the metal and more ceramic near the ceramic. Differential expansion is a big problem.

TECHNOLOGY: The Effect of Coal Gasification Atmospheres on
Biaxial Creep of Alloys

Applicable Industry; Process Element(s):

Aluminum:	4.0	Smelting
	5.0	Alloying
Cement Manufacturing:	2.0	Crushing and Grinding
Paper Manufacturing:	6.0	Paper Production
Petroleum:	4.0-7.0	Refining

Steel Manufacturing: 2.0 Smelting^(a)
Other Applicable Areas: Synfuels Production
Laboratory: INEL
Contact: G.R. Smolik
(208) 526-8317

In this DOE project, the combined effects of exposure to simulated coal gasification atmospheres and biaxial loading on structural alloy lifetime are being investigated.

The test atmosphere of the project could be especially destructive because of the coupling of stress with corrosion. The results should be especially applicable for cases where the material experiences not only corrosion but also mechanical loadings, including internal or external bursting or crushing pressures. Examples are the economizers of paper/paperboard production, the crushing and grinding operations of cement making, and reduction of iron ore in a blast furnace fired by coal (coke).

Another applicable area outside the given taxonomy is the pressure vessels and pipes/heat exchangers of the coal gasification and direct liquefaction industries.

TECHNOLOGY: Mechanical Properties Design Data - 718 Stainless Steel

Applicable Industry; Process Element(s):

Paper Manufacturing: 11.0 Chemical Recovery
Petroleum Refining: 5.0 Separation
6.0 Conversion^(a)
7.0 Chemical Treatment
9.0 Health, Safety

Laboratory: INEL
Contact: Dr. G.E. Korth
(208) 526-0348

This program is aimed at generating mechanical property (primarily fatigue and creep) design data on Alloy 718 and, to a lesser extent, type 316 stainless steel in support of the Clinch River Breeder Reactor Project and fast breeder programs in general.

Stainless steels are used in instances where corrosion resistance in addition to strength is required. Strength information, including fatigue data at long exposure times sufficient to meet the needs of the nuclear industry, would be expected to be more than adequate for the long time needs of other industries. Petroleum refining and paper production are two such industries where corrosive chemicals can be used and where the mechanical loading and cyclic loading can be severe throughout the plant. Consequently, these two industries have been identified as potentially interested in the mechanical properties of 718 and 316 stainless steel as it is being addressed by INEL.

4.7 JET PROPULSION LABORATORY (JPL)

TECHNOLOGY: Power Generation Turbine for Two Phase (gas/liquid) Fluids
in Waste Heat Streams

Applicable Industry; Process Element(s):

Paper and Allied Products:	5.0	Pulping and Bleaching
	11.0	Chemical Recovery
Petroleum Refining:	2.2	Recovery of Gas from Oil ^(a)
	6.1	Hi T&P Conversion like Thermal Cracking to Lighter Material

Laboratory: JPL

Contact: David G. Elliot
Technical Staff
(213) 354-3486

There are many pressurized, hot, two-phased, mixed fluid streams in industry that could be used for power generation, (and separation of the gas and liquid phases as well) if it were not for the fact that usually the liquid and the gas do not move at the same speed as they go through the turbine. This is called "slip" and is due to the fact that the liquid particles can neither accelerate nor decelerate as quickly as the lighter gas particles. Consequently, because turbine design and the resulting efficiency are highly dependent on fluid velocity, the design issue can easily degenerate into, "which velocity and mass flow do you try to match the design for - that of the gas or that of the liquid?" Because both are in existence, either one tends to be the wrong

choice for the other - unless the designer can find some way to separate the two fluids and extract energy from these two streams independently. If this cannot be accomplished, the usual problem in evidence is that the liquid impinges upon the rotor and the resulting wet sheets wrap around the blades and dissipate their energy in friction. In recognition of these challenges to two-phase fluids, Dave Elliot of JPL has been working for about the past 15 years in both theory and hardware to develop axial flow impulse turbines to operate at efficiencies in the 50 to 60 percent class on many types of gas/liquid streams. Elliott's technique of liquid separation differs from that of his contemporary, Lance Hays of "Biphase Energy Systems" in that Elliott's dual-fluid turbines use a first stage rotor on a separate spool moving at a relatively high rotor speed so the liquid velocity relative to the blade is quite low as is the liquid drag. The "Bi Phase" technique uses a swiftly rotating drum to impinge and collect the liquid phase.

Practical uses for dual impulse turbines to date have included geothermal steam/brine that is normally a quite hostile environment. Applications suggested in this write-up for further industrial consideration include dual phase streams in the pulp and paper industry and as a means of both separating natural gas from crude oil plus generating power in or near the well site as well as using very high pressures and temperature dual fluids from the thermal cracking process in refineries where long molecular chains are broken up into smaller (lighter) ones, some possibly gases.

Other applications suggested by Elliott include liquid-metal MHD systems, steam and oil (as in enhanced oil recovery), refrigerant expansion, solar power, transportation turbines, and engine bottoming cycles. He points out that the big advantages of two-phase turbines are that they are designed to handle liquids without erosion damage, their efficiency is not "dragged down" by the liquid and they can separate the liquid from the gas as they produce power.

References:

1. Elliot, D.G., "Theory and Tests of Two-Phase Turbines," JPL pub. 81-105, March 15, 1982.

2. Elliot, D.G., "Tests of a Two-Stage, Axial-Flow Two-Phase Turbine," JPL pub. 82-98, December 15, 1982.
3. Elliot, D.G., "Two-Phase Turbine Staging," 18th Intersociety Energy Conversion Engineering Conference, August 21-26, 1983.
4. Hayes, L., and D.J. Cerini, "Progress Report on Rotary Separator Turbine Demonstration Program," Proceedings of the Third Annual Geothermal Conference and Workshop, Electric Power Research Institute, Palo Alto, CA, October 1979, pp. 3-1 - 3-3.

TECHNOLOGY: Chemical Processes - Biocatalysis, Catalyst Modeling and Separation

Applicable Industry; Process Element(s):

Paper:	5.0	Pulping and Bleaching (biocatalysis - microbial predigestion and concentration)
	5.2	Chemical Pulping (separation - concentration methods)
	8.0	Other Cellulosic (biocatalysis - cellulose fiber from agricultural wastes)
	9.0	Waste Paper (separation - solvent extraction for waste paper recycling)
	11.0	Pollution Control
Petroleum:	4.0	Washing (separation - washing out salt waste from crude oil)
	5.0	Separation (separation - fractional distillation through separation and solvent extraction)
	6.0	Conversion (catalyst modeling - catalytic cracking) ^(a)
	7.0	Chemical Treatment (catalyst modeling)
	9.0	Pollution Control (biocatalysis - oil spill control)
Steel:	2.0	Smelting (catalyst modeling - combustion of low-Btu gases)
	4.0	Casting (catalyst modeling - low-Btu gas combustion)

Additional application areas include - genotoxic medical research, synfuels production, food processing, agriwaste, and chemicals.

Laboratory: JPL

Contact: Dr. Jovan Moacanin, Manager
Materials and Biotechnology Section
(213) 354-3178

Other knowledgeable points of contact:

J. Bailey, California Institute of Technology
E. Dunlop, Washington University
J. Eberhardt, U.S. Department of Energy (202) 252-1484
R. Gomez, Genetech Inc.
W. Weigand, National Science Foundation

(The above individuals, along with J. Moacanin, have been used as members of a "Biocatalysis Guidance and Review Panel" for JPL work and have specific knowledge of the Biocatalysis work at JPL, including technology transfer potential.)

Sponsored by the Energy Conversion and Utilization Technology Division (ECUT), Conservation and Solar Applications, U.S. Department of Energy, Dr. Moacanin's section at JPL has done substantial basic and applied research work on the subject. The ECUT program's interest occurs because of the general lack of fundamental understanding on the topic of biocatalysis and the fact that such processes have significant potential for displacing non-renewable petroleum and natural gas products with the identical products from renewable wastes from microbial action upon biomass substances ranging from sewage to cellulose, glucose and sugar. Their primary research focus has been upon resolving technical barriers to continuous biocatalysis, developing models for predicting and optimizing upon biocatalysis and lastly, to a lesser degree, establishing the feasibility of new low-energy separation techniques (needed because most processes, including biocatalysis, usually have more than one end product and they may all be highly miscible). Their overall activities on these subjects in 1982 are shown in the table below.

<u>Biocatalysis</u>	<u>Catalyst Modeling</u>	<u>Separation</u>
Kinetics for process design	Microscopic reaction Models for catalytic processes	Second law analysis
Techniques for plasmid monitoring	Electrocatalysis	Membrane technology
Cellulase hyper-production	Decarboxylation	Critical fluid extraction
Membrane fouling	Ammonia synthesis	

The technical areas where the above work may be expected to have an impact, if the technology can be transferred to these industries, are:

- Medical cancer and birth defect research where plasmids of certain types are known to determine whether or not cell production will be prone to errors. One such field may be the study of genotoxic effects due to exposure to the neutral and base fraction of synthetic fuels - most notably liquids from coal and oil shale. Also of interest may be the fact that the JPL work hinges on the catalytic properties of enzymes and trying to understand this. The point of interest is that two genotoxic classes of substances in coal liquids - polycyclic aromatic hydrocarbons and primary aromatic amines - are not mutagenic in themselves but become mutagenic in the presence of certain enzymes from the human body. JPL's work in understanding the basics of enzyme-induced reactions might be valuable to cancer researchers.
- The use of the Fischer-Tropsch class of reactions to turn CO and H₂ from coal into synfuels is normally not very selective in regard to what is produced. The catalysts used are empirically developed and very complicated. JPL's work to establish critical catalyst features and to define how to adjust them to get the desired output could be very useful in the synfuels industry.
- Hybrid chemical/biological processes are under development at JPL for the production of hydrocarbon chemicals by the removal of CO₂ from dilute acids which would leave useful chemicals such as alcohols as the product. The result of successful catalysis is believed to be about a 60 percent increase in the Btu's of fuel energy produced per Btu of energy consumed in the process. Considering that refining consumes about 0.5 quad of petroleum energy/year, the above is significant - especially if it enhances the economics of alcohol fuel production. Because both chemical and biological processes are involved, this technology should be of interest to producers of hydrocarbons who now use chemical processing and would like to improve process economics.
- The chemical industry is highly energy intensive and frequently is the highest overall annual energy consumer of all U.S. industries. JPL has determined that the highest single energy consuming step in making chemicals is in separating the one you want from the overall mix. JPL has been

working on membranes for inducing separation and has many recent accomplishments, which include: removal of acid gases from natural gas streams; separation of oxygen from nitrogen in air; separation of ethanol (or other fuels) from biomass liquor fermentation; recovery of metals from mining hydro-metallurgical leach solutions; use of "Donnan dialysis" to separate and concentrate acids, bases and salts from solutions via ion exchange; generate acids and bases via bi-polar membranes. The chemical, refining, agriwaste and synfuels refining industries should have interest in this work.

Solvent extraction at the boiling point is also a separation technique JPL has done some work on that is known as "Supercritical Extraction." In this technique, the substance you want is removed from a mix with other things by dissolving it in a solvent that is then extracted and the desired substance separated from the solvent. (Direct coal liquefaction as per the Solvent Refined Coal process or the Exxon Donor Solvent process are examples of processes using solvent extraction.) This separation technique should be of interest as a low energy consumption production method for vegetable food oils, alcohols and synfuels.

References :

1. ECUT FY 1982 Annual Report on the Chemical Processes Project, March 1983. JPL-D-599 by JPL, Cal. Tech., Pasadena, CA. (b)
2. "Biotechnology: Applications and Implications for the Pulp and Paper Industry," by Kirk, Jeffries and Leatham, TAPPI Journal, Vol. 66, No. 5, May 1983. (b)

TECHNOLOGY: Biological Enhancement of Butanol Production Processes

Applicable Industry; Process Element(s):

Paper & Allied Products:	11.0	Chemical Recovery
	12.0	Pollution Control Systems
Petroleum Refining:	2.2	Enhanced Oil Recovery ^(a)
	6.0	Conversion of Butane to Butanol

Laboratory: JPL

Contacts: Sheryl L. Bergstrom
Technical Group Supervisor
Analytical Chemistry and Bioengineering
Chemistry and Biotechnology Research
(213) 354-2496

One of the possible alternatives to capital and energy-intensive petroleum refining and cracking in the making of needed hydrocarbons and alcohols in both the chemicals and fuels fields is to let biological microorganisms feed on relatively low-cost streams of cellulose and starches ($C_6H_{10}O_5$) plus sugars ($C_6H_{12}O_6$) and produce such desirable products as butanol, methane, ethanol and acetone as a result of their life processes. Because the microbes make the conversion happen but do not enter into it themselves, such processes are known as "biocatalysis." The property of the microbes that produces this effect is their enzymes, which are simply protein molecules that promote the catalytic reaction within the cells.

One such application of "biocatalysis" is the production of n-butanol ($C_4H_{12}O_6$) alcohol from sugars by fermentation with Clostridium (a spore forming anaerobic soil bacteria) in lieu of making it by synthesis from butane (C_4H_{10}) in petroleum. Sheryl L. Bergstrom of JPL has been active in taking a fresh look at improving the natural processes to make butanol. Interested parties will find her knowledgeable and eager to help. Her work has been directed at trying to improve the yield of butanol by reducing the yield of the other products of the enzyme catalysis - acetone and ethanol. The flexibility of bioengineering in process chemistry is illustrated by the fact that her work reports upon how the metabolism of the Clostridium was shifted away from ethanol and acetate production toward butanol production. This was accomplished by using bacteria strains known as "co-cultures" which increase the production of butanol from the reduction of butyric acid made from the glucose.

According to Ms. Bergstrom, butanol is valuable as a surfactant in enhanced oil recovery. The quantities of butanol that would be required if only 5 percent of the U.S. oil production used butanol surfactants for EOR is estimated at over 2 billion pounds per year, which is at least four times the

U.S. production of n-butanol. Considering that biocatalysis could potentially displace petroleum refining as a source of butanol and considering that the petroleum refining industry is the greatest single oil consuming industry in the nation, the value of biocatalysis in petroleum conservation could be extensive.

In the pulp and paper industry, the uniform waste stream from pulping contains cellulose that would be an excellent feedstock for butanol production instead of a waste stream to be dealt with as pollutant. Additionally, each year this industry generates a higher percent of their needed heat and power from their basic feedstock - wood and chemicals from paper/pulp making. Consequently, their interests in biocatalysis could be either in fuel or chemical production or both.

References:

1. The Effect of Cocultures on the Production of Butanol by Clostridium Sp by Sheryl L. Bergstrom (JPL) and Gary L. Foutch, Chemical Engineering Department, Oklahoma State University, Scientific Note, 5th Symposium Biotechnology for Fuels and Chemicals, May 10-13, 1983, Gatlinburg, TN.

5.0 RESPONSE OF INDUSTRY TO FEDERAL MATERIALS R&D

Complications of the federal materials R&D potentially applicable to each of six manufacturing industries, arranged according to the major process elements, were sent to two to three industry representatives to obtain their comments. Below are responses of industry representatives that indicate R&D perceived as being relevant to the industry in question.

ALUMINUM INDUSTRY -

Dr. T.R. Pritchett
Vice President
Kaiser Center for Technology
PO Box 877
Pleasanton, CA 94566
(415) 462-1122

"A very useful exercise...technologies especially in Section 6.0 (Fabrication and Milling) were interesting. Variable Polarity Plasma Arc (VPPA) welding will be looked at carefully."

"We believe that this information presents a good synopsis of R&D programs being carried out today in Federal Labs, many of these are of interest to us in the aluminum industry and this compilation serves as a good media for further data. Screening and summary of such programs are always useful."

CEMENT INDUSTRY

Mr. Kenneth L. Earhard
Vice President, Cement Division
Gifford-Hill and Company, Inc
PO Box 47127
Dallas, TX 75247

"Several items are of general interest: 1. Structural ceramics, coatings for corrosion/erosion resistance, and stress corrosion research. Refractory linings in kilns, coolers, steel preheater vessels...are constantly under attack.

2. Nondestructive evaluation. This technique is used in the cement industry and (we) should be interested in any further improvements."

"The following items are of greater interest than those named above:

1. Advanced sensors. The more accurately and reliably the temperature in the kiln burning zone can be monitored, the greater is the potential for energy reduction and improvements in product quality and uniformity. Reliable gas measurement at the kiln exit on a preheater/precalciner kiln would also prove to be beneficial.

2. Industrial insulation, refractories, and recuperators. With the cement industry using more and more petroleum coke and alternate fuels, the research should prove beneficial to kiln refractory maintenance.

3. Kinetics of alternative fuels combustion. With the growing interest in using cement kilns as waste incinerators, research in this field should prove beneficial."

"Additional items of interest involve products of the cement industry. These are calcium silicate sorbent for H_2S removal and improved coal gasification processes; research and implementation of concrete-polymer overlays and patching materials; water-compatible polymer-concrete materials; and geothermal well cements. The industry should be interested in further development of those ideas to determine their practical applicability.

Mr. Jack Snyder, Manager
Construction and Geomaterials Programs
Battelle Columbus Laboratories
Columbus, Ohio 43201
(614) 424-6424

"Your report appears to be comprehensive and is quite interesting."

PULP AND PAPER INDUSTRY

Dr. Delmar R. Raymond, Director
Energy and Environmental Division
Research and Development
Weyerhaeuser Company
Tacoma, WA 98477
(206) 924-2345

"I found this as well as your previous presentation very useful, and liked particularly the tabbed notebook format organized by process activity in the most recent report. There is an amazing amount of research of which we were unaware at the Federal labs. I will divide the notebook as before and distribute it to our timber harvesting people, etc. This work should probably be repeated every three to four years. It would be appropriate to send copies to every R&D manager in the industry."

"Concerning your last year's report, I see that R&D managers including myself use it as a reference tool as new research questions arise. Our contact with Sandia, sparked by your report, has grown into two very successful joint projects using their combustion facility."

Mr. Robert A. Bareiss
Director, Process Control Technology
St. Regis Paper Company
Technical Resource Center
West Nyack, NY 10994
(914) 578-7105

"The exercise was again useful and interesting, but our review of the findings identified none requiring our immediate contact with laboratory principal investigators. Much of the materials work is too far out for our present needs. Your last year's effort probably identified the most promising matches for paper industry use."

PETROLEUM INDUSTRY

Mr. Jerry Robertson
Energy Conservation Division
Exxon Research and Engineering Company
PO Box 101
Florham Park, NJ 07932
(201) 765-0100

"The organization of the research compendium into petroleum industry activities is excellent. The write-ups are terse enough to be read quickly, yet convey the technical information. I will separate the sections and distribute them to appropriate research personnel in the company. I understand that you urge one-to-one contact with the laboratory principal investigators and will convey that thought. I am personally most interested in the corrosion technology, as that is a major concern in our industry."

TEXTILE INDUSTRY

Mr. Richard Lyons
Technical Manager, Market Research
United Merchants and Manufacturers, Inc.
PO Box 2148
Greenville, SC 29602
(803) 233-4641

"There are several projects which I feel would have pertinency for the textile industry:

1. Bearing tests data base. This could have most definite interest in textile machinery manufacturing, particularly as related to equipment in which specific stress is placed on bearings. This could include the entire range of yarn preparation equipment, particularly high-speed ring spinning frames.
2. Computer-accessible system for retrieval of tribological design data. The importance of this work has obvious relationships to the conclusions reached for the bearing tests data base. Since the first system will be introduced at the end of the current fiscal year and since this will probably concern bearing design, I am sure that the computer software generated would be of interest to the broad range of textile machinery manufacture and design.
3. Amorphous metals. This research could have application in textile production not only in the areas of production of erosion-resistant cutting blades, and surfaces, but also in components in which exposure to corrosive atmospheres is prominent. One example for this would be high-

temperature superatmospheric dying equipment in which hydrogen ions are generated. It is a well-known metallurgic fact that these hydrogen ions are extremely corrosive to all but high chromium or molybdenum content stainless steels. Consequently, this data could be of potential importance in this area.

4. Sensors. There are at least two areas in this research program which could have interest for textile technologies. The first would be non-contact optical pyrometers for measuring fabric temperatures in hostile environments such as polymerization chambers. The second would be infra-red and microwave moisture sensing devices. There has been a long-standing need in textile finishing for accurate and reliable moisture-sensing devices for use on tenter frame drying ranges.

5. ICAM. This has wide general interest for the industrial engineering segment of the textile industry. I would think the best method to exploit this within our industry would be to distribute the minutes of the June 5-9, 1983 New Orleans meeting to representative industrial engineering members of the textile industry. I had not previously heard of this meeting and I would expect that there would have been a broader textile interest if there was broader dissemination of the knowledge of the program."

Dr. Ildo Pensa, Director
Fabrics and Product R&D
Levi Strauss and Company
1900 E. Bessemen Avenue
Greensboro, NC 27405
(919) 275-9305

"Your notebook contained some information of interest to us. The work on advanced sensors, for example, would be useful. Most of the reported work, however, is quite advanced research and its implications were not always obvious, e.g., the coatings and adhesives items."

APPENDIX A: INDUSTRY TAXONOMIES

TAXONOMY OF ALUMINUM PRODUCTION

1.0 MINING AND TRANSPORTATION

This element includes equipment and activities involved in mining bauxite ore in open pits and transporting it by truck or rail to the processing plant.

2.0 BAUXITE PROCESSING

This element includes equipment and activities involved in crushing, washing, kiln-drying, and pulverizing bauxite ore.

- 2.1 Crushing - Includes equipment and operations used in crushing bauxite ore for easy handling.
- 2.2 Washing - Includes equipment and operations used in freeing bauxite ore from clay and dirt.
- 2.3 Kiln-Drying - Includes equipment and operations involved in drying bauxite.
- 2.4 Pulverizing - Includes equipment and activities associated with fine grinding of bauxite ore.

3.0 ALUMINA REFINING

This element is concerned with the production of pure alumina and includes such activities as mixing, digesting, clarification, precipitating, and calcination of bauxite ore.

- 3.1 Mixing - Includes equipment and activities associated with the mixing of finely ground bauxite ore under steam heat and pressure by the Bayer process.
- 3.2 Digesting - Includes operations, large tanks, and other equipment used in dissolving bauxite ore under steam heat and pressure by the Bayer process.
- 3.3 Clarification - Addresses equipment and activities used in thickening, filtering, and cooling of the sodium aluminate solution. Equipment used in the clarification process includes a series of pressure reducing tanks and filter presses. The impurities are known as red mud.
- 3.4 Precipitation - Pumps, cooling towers, or heat exchangers, and large, silo-like precipitators are used in this process that agitates and seeds the solution with crystal aluminum hydrate which helps to speed crystal separation of hydrated oxide. Alumina trihydrate falls to the tank bottom. Finally, the hydrated crystals are washed to remove insoluble impurities.
- 3.5 Calcining - This activity is concerned with the operations and rotary kiln drying equipment leading to transformation of hydrated oxide to cooled anhydrous alumina, a white powder.

4.0 SMELTING

The Hall-Heroult electrolytic process is the basis of alumina reduction in today's aluminum industry. This element includes equipment and activities used by this process for the electrolytic reduction of alumina in a molten cryolite bath at 1800°F to obtain pure aluminum.

4.1 Transportation - Alumina is transported to the smelting cell with air slides or closed air suction systems integrated with antisegregation devices.

4.2 Smelting - The carbon-lined, cast-iron shell of the smelting cell, or pot, serves as the cathode. Carbon rods suspended in the electrolyte serve as the anode. Current passing through the electrolyte separates the dissolved aluminum oxide into metallic aluminum, which falls to the bottom, and oxygen, which is deposited on the carbon anodes and gradually consumes them.

5.0 ALLOYING

This element includes equipment and materials utilized in remelting, purification, degasification, and alloying. Remelting furnaces (alloying furnaces) are generally charged with a combination of primary aluminum and recycled scrap of known chemical composition. Principal alloying metals are copper, silicon, manganese, magnesium, zinc, iron, and chromium. After appropriate treatment of the melt, the metal is filtered to remove inclusions and is cast in a semi-continuous manner in vertical, water-cooled molds. Some aluminum alloys can be hardened by heat treatment.

6.0 FABRICATION AND MILLING

6.1 Fabrication - Includes equipment and activities leading to the production of two general classes of materials fabricated during aluminum processing: foundry products and wrought products.

6.1.1 Foundry Products - Foundry products are those cast from molten alloy directly to shape. There are three processes used in casting these products: die casting, permanent mold casting, and sand casting.

6.1.1.1 Die Casting - Involves equipment and activities for products requiring greatest accuracy of dimension, surface finish, and detail. The process is best suited for high production rates and casts parts as large as 45 kg (100 lb).

6.1.1.2 Permanent Mold Casting - Includes equipment and activities used in a process that is suited for large production runs and castings of up to 200 lbs. with superior mechanical properties due to the rapid chilling effect of contact with the metal mold.

6.1.1.3 Sand Casting - Includes equipment and activities leading to casting large products of up to 18,000 lbs. weight and which utilizes a sand and resin mold.

6.1.2 Wrought Products - Wrought products are shaped by plastic deformation through mechanical working which is accomplished by two major processes known as hot and cold working.

6.1.2.1 Hot Working - Includes equipment and activities leading to deformation of metal above a spontaneous recrystallization temperature. Most hot working is done in a temperature range from 600°F to 1000°F.

6.1.2.2 Cold Working - Includes equipment and activities involved in deformation of metal below the recrystallization temperature but not necessarily under room temperature.

6.2 Milling - Includes two basic milling facilities, namely, the rolling mill and the extrusion mill, as well as joining and finishing operations.

6.2.1 Rolling Mill Process - Includes equipment and activities involved in: (1) soaking, preheating and preliminary reduction of dc (direct chill) ingots to a slab of 3- to 8-inch thickness; (2) reheating, trimming, and rerolling down to one-inch thickness; and (3) subsequent annealing and rolling to .008- to .375-inch thickness. The common products of this process are sheet, plate, and foil.

6.2.2 Extrusion Mill Process - Includes equipment and activities used in extrusion of an ingot or billet which is placed under pressure in a chamber that is effectively closed except for a die opening. The process may be forward (direct) or backward (indirect) extrusion and can be performed either hot or cold.

6.2.3 Joining and Finishing - Joining of aluminum is accomplished by riveting, welding, or brazing. Principal welding techniques are torch- or fusion-welding with use of a suitable flux, inert gas shielded arc welding, and electric resistance (usually spot-) welding. Finishing methods vary widely, and include anodizing, painting, lacquering, electroplating and buffing.

7.0 PROCESS CONTROL SYSTEMS

This element includes activities and equipment associated with process monitoring techniques, quality controls, sensors and energy auditing techniques.

8.0 HEALTH, SAFETY, AND POLLUTION CONTROL SYSTEMS

This element includes activities leading to control, treatment, and disposal of air, water, and solid waste streams generated by aluminum manufacturing processes. Also included in this element are health and safety concerns.

9.0 SCRAP

This element includes new (generally consists of runaround scrap or scrap purchased from nonintegrated fabricators) and old (scrap from obsolete components) scrap.

TAXONOMY OF CEMENT PRODUCTION

1.0 QUARRYING AND TRANSPORTATION

- 1.1 Quarrying - Includes equipment and operations involved in strip mining of calcareous rock (CaCO_3) which is the principal ingredient of cement. Electric or diesel power shovels, drag-line excavators, and front-end loaders are the common equipment used in this operation.
- 1.2 Transportation - Includes activities and equipment used in loading and transporting broken rocks to crushing sites. Diesel trucks of up to 65 tons are the primary means of transportation.

2.0 CRUSHING AND GRINDING

- 2.1 Crushing - Includes equipment and operations used in crushing broken stones to less than 0.75-inch diameter. This activity is completed in two separate processes. First, the broken stone is crushed in a gyratory, jaw, or roller crusher to pieces about 6 inches in diameter and then is further crushed in a hammer mill impactor, or cone crusher to less than 0.75-inch diameter. If the broken stone has more than 6 percent moisture, a crusher with heated dryer parts is used.
- 2.2 Grinding - Includes equipment and activities that intergrind broken rocks with SiO_2 , Al_2O_3 and Fe_2O_3 . Raw materials with water content of up to 38 percent are interground in the wet process, such that the final grinding and blending is carried out in a water slurry. After the water is partially removed by various processes (gravity-settling of the solid in a thickener, filtration through canvas covered rotating drums, and evaporation using various heat exchangers), the final product is directly fed to the kiln or through a preheater. Raw materials for the dry process, on the other hand, can be interground by a ball, rod, or roller mill and then fed to the kiln system as a meal.

3.0 PYROPROCESSING

This element includes activities and equipment associated with the heating of raw materials to approximately 1400°C to produce clinker. Kilns of various types are the primary equipment used in this operation. The shaft or vertical kiln is extensively used in Europe due to its greater fuel economy, while rotary kiln has completely replaced vertical kilns in the U.S. due to its superior production qualities. However, it has been claimed that recent improvements on the vertical kiln make the kiln more competitive with rotary kiln with respect to uniformity and quality of clinker produced.

4.0 CLINKER COOLING

The rapid cooling of the clinker is important because slow cooling may cause dusting; slow cooling may also result in problems such as: (1) flash setting of the cement after it has been ground with gypsum, (2) weakening and disintegration of the concrete if the clinker is relatively high in MgO , and (3) concrete with reduced resistance to sulfate

solutions. There are two primary types of coolers currently used by the industry: the air quenching cooler and the rotary coolers.

4.1 Air Quenching or Grate Cooler - The grate cooler transports the clinker with traveling grates inside several compartments during the cooling process. It has two primary variables, air distribution and clinker distribution. Air distribution is controlled by separate fans in the various compartments. The hot clinker falls first onto a narrow, slow moving grate where maximum heat recovery occurs. The thickly distributed clinker is then transferred to a faster moving, wider grate to complete the cooling process.

4.2 Rotary Cooler - The rotary cooler is similar to a kiln in that it rotates and has definite zones.

5.0 FINAL GRINDING

This element includes activities and equipment involved in the inter-grinding of clinker with an average of 5 percent gypsum ($\text{CaSO}_4 \cdot \text{H}_2\text{O}$) or other materials to produce the finish cement. Ball mills and roller mills are used for grinding clinker.

6.0 PROCESS CONTROL SYSTEMS

This element includes activities and equipment associated with such operations as monitoring techniques, quality controls, energy auditing techniques, sensors.

7.0 HEALTH, SAFETY, AND POLLUTION CONTROL SYSTEMS

Activities leading to: (1) control, treatment, and disposal of air, water, and solid waste streams, (2) noise abatement, and (3) health and safety are included in this element.

TAXONOMY OF PULP AND PAPER PRODUCTION

1.0 TREE SEEDLING PRODUCTION AND GENETIC DEVELOPMENT

This element includes forest nursery, tree seed gathering, and seed genetic selection and improvement activities.

2.0 FOREST LAND PREPARATION, STOCKING AND YIELD MANAGEMENT

This element includes activities and equipment associated with the preparation of cut over land or cleared land, the planting of seed or seedlings and the management of forest land for enhanced fiber yield.

- 2.1 Forest Land Preparation - Includes the equipment and operations involved in the preparation of forest soil, including clearing, grading, fertilizing, tilling, watering and erosion control.
- 2.2 Stocking - Includes the equipment and operations involved in planting seeds and seedlings.
- 2.3 Yield Management - Includes the equipment and operations used to enhance and protect fiber yield, such as insect and pest management, fire control, supplemental irrigation and fertilization, inventory and growth measurements, timber valuations, and harvest scheduling.

3.0 TIMBER HARVESTING, TRANSPORTATION AND STORAGE

This element includes activities and equipment involved in the cutting of standing timber, removing limbs and foliage, sizing, yarding, transporting, weighing/scaling, and storing pulpwood.

- 3.1 Harvesting - Includes the equipment and operations used to cut, process and yard standing timber. Includes equipment such as saws, slash chippers, skidders, and stackers.
- 3.2 Transportation - Includes the equipment and operations used to transport pulpwood or pulpwood products from forest lands to pulp mills. Includes trucks, waterways and rail.
- 3.3 Storage - Includes the equipment and operations involved in the weighing or scaling of pulpwood or pulpwood products and the storage of pulpwood at the mill site.

4.0 DEBARKING AND CHIPPING/GRINDING

This element includes activities and equipment involved in the removal of pulpwood bark and the conversion of debarked pulpwood to chips or ground fiber.

- 4.1 Debarking - Includes equipment and operations for the removal of pulpwood bark and the recovery of byproduct bark material. Both wet and dry debarking processes are presently being used.
- 4.2 Chipping/Grinding - Includes equipment and operations involved in the conversion of roundwood to chips or ground fiber. Process steps

would include chipper/grinder, screening, fines for recovery as fuel and accepts to storage.

5.0 PULPING AND BLEACHING

This element includes activities and equipment involved in the mechanical and chemical pulping of wood and the bleaching of pulped wood fiber.

5.1 Mechanical Pulping - Includes equipment and operations for the production of pulp by mechanical methods. Processing steps include washing, refining, screening, dewatering, rejects recovery and slash pulp storage.

5.2 Chemical Pulping - Includes equipment, chemicals and operations for the production of pulp by chemical methods including byproduct energy recovery and chemical recovery. Process steps include digestors, chemical addition, water treatment, refiners, washers, shredders, chemical recovery and byproduct energy recovery.

5.3 Bleaching - Includes equipment and operations for the production of bleached pulp including chemicals, water treatment, washing and storage of bleached product.

6.0 PAPER/PAPERBOARD PRODUCTION AND COATING

This element includes activities and equipment involved in the manufacture and coating of paper and paperboard products including chemical additions, water treatment, cleaning and washing steps, coloring, screening, Fourdrinier, pressing, drying, sizing and rolling.

7.0 COATING, CONVERTING

This element includes equipment and operations involved in the coating and converting of primary paper and paperboard including chemicals, adhesives, cleaning and washing steps, coloring, all coatings, water treatment, drying, sizing and rolling.

8.0 OTHER CELLULOSE FIBER SOURCES

This element includes equipment and activities associated with the development of other cellulose fiber sources (e.g., cotton gin wastes, kudzu and Ag wastes).

9.0 WASTE PAPER

This element includes equipment and operations associated with collection, transportation and recycling of waste paper.

10.0 PROCESS CONTROLS

This element includes such operations as monitoring techniques, quality controls, energy auditing techniques, sensors, and material inventories.

11.0 CHEMICAL RECOVERY

This element includes activities and equipment involved in chemical recovery including black liquor processing, lime kiln and recovery furnace operations.

12.0 POLLUTION CONTROL SYSTEMS

This element includes activities involved in the control, treatment and disposal of air, water and solid waste streams from papermaking operations.

TAXONOMY OF PETROLEUM PRODUCTION

1.0 EXPLORING

This element includes equipment and activities associated with scientific methods of increasing the probability of discovering a productive reservoir before drilling. Geological investigations are made on outcropping strata of rocks near a proposed drilling site for indications of the structure and characteristics of the layers of rocks buried beneath the surface. To find subsurface indications, geophysical methods are practiced using such equipment as the magnetometer, gravimeter, and seismograph.

2.0 DRILLING AND PUMPING

2.1 Drilling - Includes equipment and activities involved in drilling wells into the depth of the earth. Wells are drilled either by cable-tool or rotary drilling methods.

2.1.1 Cable-Tool Drilling Method - Employs a heavy cutting tool called a bit which pulverizes the rock formation a little at a time when it is alternately raised and dropped.

2.1.2 Rotary Drilling Method - Most wells are presently drilled by the rotary drilling method which consists of revolving a steel bit at the bottom of the hole. The revolving action breaks up the hard rock by chipping, cutting and abrasion.

2.2 Recovery - Includes activities and equipment used in the production of oil and gas from the wells after casing and tubing are in place. Gate valves and piping are installed above the ground (and are called a Christmas tree). After the crude oil and entrained natural gas are brought to the surface, the gas is separated from the crude oil before shipment.

3.0 TRANSPORTING

This element includes activities and equipment utilized in providing links between oil wells and refineries. Common equipment used in this operation are tankers, barges, and pipelines.

4.0 WASHING

This element includes activities and equipment associated with washing and removing salt from crude oil with clean water under pressure at about 250°F. Detergents or electromagnetic fields are used to improve salt water and oil separation.

5.0 SEPARATION

Major separation processes include fractional distillation and solvent extraction.

5.1 Separation by Fractional Distillation - Includes equipment and activities associated with distillation processing of crude oil. The

components, or fractions, in the crude mixtures boil or vaporize at different temperatures, and the vapors are collected and condensed at separate points in the process.

- 5.2 Separation by Solvent Extraction - This process uses a suitable solvent that when mixed with a petroleum fraction dissolves some constituents but not others. Separation is then achieved by settling into layers.

6.0 CONVERSION

This element includes equipment and activities involved in conversion processes which change the less valuable fractions from distillation into more valuable products such as gasoline. The main conversion processes are thermal cracking, catalytic cracking, polymerization, alkylation, hydrogenation, and reforming.

- 6.1 Thermal Cracking - The thermal cracking process is accomplished by heating heavy oil fractions to high temperatures under high pressures, where the long hydrocarbon chains break up into shorter chains suitable for gasoline, heating fuel, or diesel oil.
- 6.2 Catalytic Cracking - Catalytic cracking is like thermal cracking, except that catalysts are used to facilitate the conversion of heavier molecules into lighter, more desirable products. High temperatures are needed, but pressures can be moderate.
- 6.3 Polymerization - Polymerization is the combining of small hydrocarbon molecules into larger ones. In this process, refinery gases of relatively low value are subjected to high temperatures and pressures, which polymerize the light gas molecules into liquid products or polymers.
- 6.4 Alkylation - This process is applied to highly volatile hydrocarbons produced in the cracking operation to convert them into lower volatile materials of higher octane number. Ethylene, propylene, butane, and isobutane cannot readily be used as gasoline components unless treated by alkylation.
- 6.5 Hydrogenation - In this process hydrogen is added to the heavier fractions during cracking which helps to convert the heavier fraction to lighter, more desirable products.
- 6.6 Reforming - Reforming is a cracking process used for obtaining special products such as toluene for the production of TNT and to increase the production of high-octane gasoline. Reforming is also used to produce benzene and xylene.

7.0 CHEMICAL TREATMENT

This element includes equipment and activities associated with the removal of objectionable impurities by chemically treating the fraction to improve the qualities of lubricating oil and other refined products. In addition, this process is used to improve gasoline properties of color, odor, and resistance to deterioration and corrosion.

8.0 PROCESS CONTROL SYSTEMS

This element includes equipment and activities involved in process monitoring techniques, quality controls, sensors and energy auditing techniques.

9.0 HEALTH, SAFETY, AND POLLUTION CONTROL SYSTEMS

This element includes equipment and activities associated with the control, treatment, and disposal of air, water, and solid waste streams generated by the petroleum refining industry. Crude oil spillage and their cleaning techniques, such as skimming and sorbent materials, are also covered. In addition, this element includes health and safety concerns.

10.0 USED OIL

This element includes equipment and techniques utilized in collection, transportation, and recycling of used oils.

TAXONOMY OF STEEL PRODUCTION

1.0 AGGLOMERATION

Iron ore concentrates are agglomerated to prevent ores from flying out the blast furnace. In general, the coarser concentrates can be sintered and the finer ones pelletized. There are four common processes in agglomerating iron ore concentrates: sintering, nodulizing, briquetting, and pelletizing.

- 1.1 Sintering - Iron ore concentrates are mixed with pulverized coal or coke breeze, recycle sinter fines, and some moisture. The mixture is placed on a moving grate and the top surface is ignited. The burning zone progresses downward through the bed and when it reaches the bottom the reaction is completed. Later, the sinter is cooled and discharged.
- 1.2 Nodulizing - In the nodulizing process, iron ore concentrates are mixed with limestone and fed to a rotary kiln fired with pulverized coal.
- 1.3 Briquetting - Binders such as cement, sulfite liquor, and iron sulfate solution have been used in briquetting iron ore concentrates, but the resulting briquettes are not strong enough for blast furnace use. Both hot and cold briquetting have been tried by the industry.
- 1.4 Pelletizing - Pelletizing consists of forming green balls from a mixture of the fine concentrates and binder (i.e., bentonite) at room temperature and then hardening them by heat treatment. There are four types of furnaces used in heat treating green balls: shaft furnace, Dravo-Lurgi traveling grate, the Allis Chalmers grate kiln system, and the McKee circular grate.

2.0 SMELTING

The process of reduction of iron ore to pig iron is known as smelting and is carried out in the blast furnace which reduces iron oxide to elemental iron by reaction with hot carbon and carbon monoxide. Coke, limestone, iron-bearing raw materials, and heated air are the principal materials fed into the furnace.

3.0 STEELMAKING

Generally, hot liquid metal generated by the blast furnace is transferred in ladles or refractory-lined cars to one of three commonly used steelmaking process facilities, where carbon, silicon, and other impurities are oxidized from the metal phase. These facilities include the basic oxygen furnace, electric arc furnace, and open hearth furnace.

- 3.1 Basic Oxygen Furnace (BOF) - In basic oxygen furnace steelmaking, pure oxygen under pressure is blown into a vessel containing hot metal and scrap. During the oxygen-introducing period, which lasts about 25 minutes, lime and other fluxes are put into the furnace to assist in the formation of a slag containing the oxidized Si, Mn, P, and S. The scrap portion of the charge is normally limited to a maximum of about 30 percent.

- 3.2 Electric-Arc Furnace - The charge for this type of furnace consists primarily of steel scrap and perhaps a small addition of pig iron. Electric-arc furnaces used by industry are three-phase types and are equipped with three electrodes which enter through the roof. Furnaces are of both acid and basic types.

4.0 CASTING

This element includes activities and equipment leading to casting molten steel by either one of two processes: ingot casting or continuous casting.

- 4.1 Ingot Casting - Molten steel tapped in ladles is poured into ingot molds of various designs and dimensions to solidify and is later stripped from the molds and placed in fuel-heated soaking pits. The soaking pit ensures a uniform ingot temperature for subsequent rolling to produce slabs, billets or blooms.
- 4.2 Continuous Casting - A newer process that is designed to eliminate blooming, slabbing, and roughing operations by casting directly from the melting furnace, roll-squeezing, cooling, and cutting in a continuous cycle. However, not all steel can be continuously cast.

5.0 FABRICATION

This element includes such primary operations as rolling, forging, and extrusion and other operations such as galvanizing, shearing, cleaning, and annealing. The final products are structural shapes, rails, bars, wire, pipe, sheet, or strips.

- 5.1 Rolling - Includes activities and equipment involved in reducing cross section and increasing length of an ingot by repeatedly passing it between two rolls. Operation can be performed by either cold or hot rolling.
- 5.2 Forging - Includes equipment and activities leading to hot working of ingot by hammering and pressing. Forging processes are carried out by three types of forging equipment: forging hammers, known as drop hammers; forging presses; and forging machines which have dies operating through a horizontal plane rather than a vertical plane.

6.0 PROCESS CONTROLS

This element includes such operations as monitoring techniques, quality controls, energy auditing techniques, sensors, and material inventories.

7.0 HEALTH, SAFETY, AND POLLUTION CONTROL SYSTEMS

Includes activities leading to the control, treatment and disposal of air, water and solid waste streams; and health and safety.

8.0 COKE MAKING

In this process coal is converted to coke in a large, externally heated oven which drives off the volatile materials contained in the coal. A solid product is created (coke) that can withstand the high temperatures and tremendous crushing pressures found in the blast furnace.

9.0 SCRAP

Includes both new scrap (runaround scrap) and old scrap (from outside the steel industry).

TAXONOMY OF TEXTILE PRODUCTION

1.0 FIBERS

Almost all fibers are made of textile fibers which are classified in one of two main categories: natural or man-made.

- 1.1 Natural Fibers - The natural fibers consist of three classes based on chemical structure: (1) protein (animal), of which wool and silk are best known; (2) cellulosic (vegetable), of which cotton, linen, and jute are most widely used; and (3) mineral, of which asbestos is the only fiber.
- 1.2 Man-Made Fibers - The man-made fibers may be placed in one of two categories on the basis of their sensitivity to heat. The thermoplastic fibers -- for example, acetate, nylon, polyester, olefin, acrylic -- soften and become pliable on contact with heat of lower temperatures. The non-thermoplastic fibers -- rayon, glass, metallics -- do not soften or become pliable at temperatures encountered in homes or businesses.

2.0 YARN MAKING

Fibers are required to be made into yarns before they can be used in fabric construction. This element includes activities and equipment used in processing fibers to yarn which may be specific to one or common to several fibers.

- 2.1 Preprocesses - The preprocesses for some of the most common natural fibers are: (1) for cotton -- picking, ginning, baling, and classifying as to grade, staple, and character; (2) for linen (flax) -- pulling, rippling, retting, decortication, breaking and scratching; (3) for wool -- shearing, or pulling, grading, sorting, scouring, burr picking, and carbonizing; and (4) for silk -- reeling and degumming. Man-made fibers, on the other hand, do not need preprocessing as they are manufactured clean and ready for yarn production.
- 2.2 General Processes - Include equipment and activities associated with general processes that are common to many staple length fibers and that include such operations as opening and blending, carding, combing, drawing, spinning, and winding. In addition, many yarns may require texturizing which adds bulk or stretch or reduces opacity, or provides a combination of these.

3.0 FABRIC CONSTRUCTION

- 3.1 Yarn Fabrics - Includes equipment and activities used in manufacturing fabrics that require yarns in their intermediate step of production and include such fabrics as woven, knitted, braided, net, and lace.
- 3.2 Non-Yarn Fabrics - Include activities and equipment used in production of fabrics that are directly made from fibers. These fabrics include such products as felt, bonded nonwovens, needle-

punched webs, stitch-bonded sprayed fiber, and laminates.

4.0 FABRIC FINISHING

This element includes activities and equipment used in finishing processes which are aimed at improving fabrics' appearance, service qualities, or both. General finishing processes are cleaning, bleaching, drying, heat-setting (for thermoplastics), inspection, repair, singeing (burning off fuzzy fiber ends), shearing, brushing, potting, preshrinking, mercerizing (to add luster, strength, and absorbency), sizing (to add stiffeners), weighting and fulling (to add the body), tentering, dyeing, and application of design.

5.0 PROCESS CONTROLS

This element includes such operations as monitoring techniques, quality controls, energy auditing techniques, sensors, and material inventories.

6.0 HEALTH, SAFETY, AND POLLUTION CONTROL SYSTEMS

Includes activities leading to the control, treatment, and disposal of air, water, and solid waste streams; and health and safety.

DISTRIBUTION

No. of
Copies

OFFSITE

William B. Williams
U.S. Department of Energy
Office of Industrial Programs
Forrestal Building
Washington, D.C. 20585

John Rossmeissl
U.S. Department of Energy
Office of Industrial Programs
Forrestal Building
Washington, D.C. 20585

James Demetrops
U.S. Department of Energy
Office of Industrial Programs
Forrestal Building
Washington, D.C. 20585

Al Hayes
U.S. Department of Energy
Office of Industrial Programs
Forrestal Building
Washington, D.C. 20585

Al Streb
Deputy Assistant Secretary for
Conservation
U.S. Department of Energy
Forrestal Building
Washington, D.C.

No. of
Copies

OFFSITE

27 DOE Technical Information Center

100 Jim Reed
Energetics, Inc.
9210 Route 108
Columbia, MD 21045

ONSITE

DOE Richland Operations Office

H. E. Ransom/D. R. Segna

26 Pacific Northwest Laboratory

C. H. Bloomster
M. Clement
R. M. Fleischman
B. A. Garrett-Price
N. L. Moore (15)
Publishing Coordination (2)
Technical Information (5)