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**Title:** LANL/UTEP Metallurgical Science Center of Excellence Planning


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**Intended for:** Collaborative project between the Department of Metallurgical, Materials and Biomedical Engineering at the University of Texas at El Paso (UTEP) and the Technical Operations Office (TAO) of Associate Laboratory Directorate of Weapons Production (ALDWP) at the Los Alamos National Laboratory (LANL).


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# LANL/UTEP Metallurgical Science Center of Excellence Planning

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**UNCLASSIFIED**
**Name/Org: Thomas Gunderson/ALDWP-TAO**
**Date: 07/27/2023**
**Guidance (if applicable): n/a**

# High Level Technology Needs

## Pit Technologies

- Electrorefining Operations
- Foundry Operations
- Metal Production
- Pyrochemical Processing
- Plutonium Machining
- Inspection / NDE
- Product Engineering
- Welding

## Plutonium 238 Technologies

- Ceramics Properties
- Sintering
- Powder Processing
- Radioisotope Thermal-Electric Generators
- Non-Destructive Examination
- Precision Welding

## Disassembly Technologies

- Machining
- Robotics
- Radiation Minimization
- Materials Disposition
  - Uranium
  - Beryllium
  - Contaminated Materials

## Waste Management

- Solid Waste
  - RCRA
  - LLW
  - HLW
  - TRU
- Liquid Waste
  - Sanitary
  - Liquid Decontamination
  - Solidification Technologies
- Radiation Control
- WIPP WAC

## Nuclear Materials Management

- Materials Control & Accountability
- Legacy Materials
- Material Protection


# Define Opportunities

**Potential 3-Year University of Texas at El Paso Scoping Statement (FY23 – 26)**

Estimate at completion $3M

August 30, 2022

LANL seeks research assistance and skills development in three distinct subject areas over the next three years. Individualized scope and detail implementation schedules will be the first deliverable for these subject areas and will represent a joint determination between LANL SMEs and UTEP faculty based on LANL priority (schedule) and UTEP staffing (faculty and student – graduate and undergraduate) and capability of immediate availability per schedule. LANL will endeavor to make summer internships available to UTEP students within these subject areas: Chemical Sciences, Additive Manufacturing, and Metallurgy: casting and solidification, characterization, and metal purification.

Unarticulated but generalized scoping tasks follow within each topical area to indicate that students and technicians familiar with these skill sets are of value and interest in LANL workforce pipeline and the tasks that seek to develop these skill sets are intentional on LANL's part. Consequently, LANL will sponsor 2-3 senior (capstone) projects withing these subject areas per year over the three year time period within these task areas and within separations technologies, wet chemical analysis, and analytical characterization and quantification as required by all tasks.

**Chemical Sciences, Additive Manufacturing, and Metallurgical Characterization of Materials and Prototypes**

**Task 1:** Research pertaining to chemical and radiation compatibility of a list of stereolithography/digital light processing (SLA/DLP) printed materials used by LANL for chemical processing applications.

Given new focus on additively manufacturing flow devices for a variety of chemical processes supporting actinide material processing, we would like data pertaining to the solvent and radiation compatibility of these proposed materials. Tests of interest would include, but are not limited to, understanding degrading mechanical properties (e.g., elastic moduli, ultimate tensile strength, creep), chemical reactivity (e.g., leaching of chemicals from the printed material into the solvents, swelling of the part material by the solvents), and radiation integrity (e.g., degradation of the mechanical properties listed above under LANL-defined environments/radiation doses, off-gassing produced during irradiation). A list of commercially available printable materials and solvents of interest as well as expected lifetime of exposure will be provided by LANL.

- Area of specialization: Mechanical and Chemical testing

**Task 2:** Research pertaining to novel material development for SLA/DLP printable resins that are particularly resistant to chemical degradation

To our knowledge, no commercially available SLA/DLP resins exist that are specifically designed to be resilient to chemical and radiation degradation in the required environments of actinide processing at LANL. We would like a resin that is printable on LANL-specified commercially available SLA/DLP printers (LANL will ensure that UTEP has desired printing capability in place) that outperforms commercially available resins in testing defined in Task 1. Research may include, but is not limited to, the following: a) a thorough review of commercially available resins that may have properties superior to the materials



listed by LANL in Task 1, and/or b) synthetic development of a novel photocurable material that has superior properties when tested as performed in Task 1.

- Area of specialization: Photochemistry, polymer synthesis

**Task 3:** Research pertaining to additively manufacturing titanium alloys and metal-polymer composites for customized designs

Certain projects under development at LANL require customized components that need to withstand highly corrosive solutions that contain highly abrasive particles. LANL also has the need for integrating shielding into certain systems to reduce worker dose. LANL would like UTEP to explore the possibility of printing certain components out of refractory alloys (Ti, W, Nb, V), and possibly printing in metal and polymer layers. Certain components could be as big as ~18-24" H x 5-6" W/D.

- Area of Specialization: Design for manufacturing in metal

**Task 4**: Research defining optimal interfacing between fluidic and mechanical components

Many of the additively manufactured solutions for chemical processing need to be interfaced with fittings commonly used in fluidic systems, e.g., High-Performance Liquid Chromatography (HPLC) systems. However, given the tendency for embrittlement and surface roughness of the SLA/DLP printed materials, these fitting connections sometimes lead to cracking of the material upon tightening or leaking around the fitting seal surface. We would like design-rules for the best sealing connections between tubing and 3D printed parts or between two 3D printed parts, e.g., gaskets. Additionally, many of the printed SLA/DLP parts must be mechanically connected to supporting structures, e.g., a fused filament fabrication (FFF) printed component. Again, the brittle nature of these SLA/DLP parts make mechanical connections difficult. We would like design rules for how to best make connections between SLA/DLP components and other metal or plastic parts that will lead to secure mechanical connections without putting stress on the SLA/DLP printed parts.

- Area of specialization: Mechanical and Chemical Engineering

**Task 5:** Cooling rate characterization of simplified molds.

In the foundry we are trying to determine what controls cooling rates during mold-filling, during solidification, and during mold cool-down to ambient. Potential factors include size of the mold, mold coatings, mold shape and surface area, heat sinks (both through thermal conduction and radiative), vacuum level. We seek research into determining the significance of each of these parameters in our system, as well as methodologies to better predict cooling rates. Especially if the expected cooling rate changes significantly throughout mold locations. The end goal is to better facilitate a rapid cooling rate, uniformly if possible.

- Area of specialization: Finite Element Modeling

**Task 6:** Comparison of creep, temperature cycling of Glidcop© to copper (this might seem obvious but after extended cycles the oxide that keeps the grain smalls might diffuse and grow rendering the grain pinning ineffective).

We have recently procured a Glidcop© Induction coil (https://en.wikipedia.org/wiki/Glidcop). There is a question whether repeated temperature cycling of the coil in our current configuration will cause the



coil to lose strength due to grain diffusion. This would involve repeated temperature cycling of a sample coil section, along with associated mechanical properties testing.

- Area of specialization: Physics and Mechanical Engineering

**Task 7:** Comparison of oxide thickness on tantalum crucibles versus its emissivity or its gray body response.

Our melt crucibles are made of tantalum. To minimize adhesion the crucibles are heated in air producing a tantalum oxide surface resulting in a coloration change from silver to deep blue. During the casting process, we measure the temperature of these crucibles using a 2-color pyrometer. There is a question of whether the oxide thickness affects the emissivity of the tantalum crucibles, and if it is potentially affecting pyrometer readings. This study involves preparing samples of Ta with varying thicknesses of tantalum oxide, measuring the thickness, and determining emissivity at different wavelengths.

- Area of specialization: Surface Science

**Task 8:** Simulation of grain-growth and microstructure within cast parts, varying cooling-rates, and purities. LANL will provide the essential parameters needed for the simulation.

LANL is interested in knowing what parameters affect grain growth and microstructures, and to what degree they are important (LANL based work).

- Area of specialization: Physical Metallurgy

**Task 9:** Composite research regarding additive manufacturing of a tantalum fixtures currently used in manufacturing. These include the funnel, distributer, and molds. We would like research on a variety of base materials that may be used to reduce the amount of tantalum required and meet product performance needs. LANL is very interested in having tantalum or tantalum oxide as a liner.

- Area of specialization: Materials Science

**Task 10:** Mold Coating Research

Research in a variety of release agents to determine their effectiveness prevent mold sticking, facilitating filling of the pour, chemical compatibility. We currently use calcium difluoride as our mold coating for graphite molds. We would like for UTEP to consider research into improved coatings.

- Area of specialization: Ceramics

**Task 11:** Mold Material Research

Research into mold materials that are resistant to Pu corrosion, compatible with Pu criticality safety concerns, conductive enough to work in our induction heat furnace, and reusable. In the past, research into replacing graphite molds with metal molds resulted in the need for a ceramic coating on the metal to prevent corrosion by the molten Pu.

- Area of specialization: Chemical Engineering

# Analysis of Needs and Course Offerings

**Metallurgy and Materials Science at Los Alamos National Laboratory**

| **Metals of Interest** | | |
|---|---|---|
| **TOPIC** | **APPLICATION** | **LANL/UTEP Collaborations** |
| • Plutonium | • Weapons<br>• Space Program Power | • LANL is the US Plutonium Center of Excellence |
| • Uranium | • Weapons<br>• Nuclear Power | • We work with this material routinely |
| • Beryllium | • Heat Capacity<br>• Low Density<br>• High Strength<br>• Space Applications | • We work with this material occasionally |
| • Titanium | • High Strength<br>• Low Density | • Task 3 |
| • Stainless Steels | • All | • We work with this material routinely |
| • Refractory Metals<br>○ Tantalum<br>○ Tungsten<br>○ Vanadium<br>○ Niobium | • Crucibles<br>• Fixtures<br>• Role of oxide surface in crucibles | • Task 3<br>• Task 7 |

| **Capstone Projects** | | |
|---|---|---|
| **TOPIC** | **APPLICATION** | **LANL/UTEP Collaborations** |
| • Glovebox Design | • Improved working conditions in GBs | • Fall 2022/Spring 2023 |
| • TBD | • Product or Process Improvement | • Fall 2023/Spring 2024 |

| **Waste Management** | | |
|---|---|---|
| **TOPIC** | **APPLICATION** | **LANL/UTEP Collaborations** |
| • Waste Minimization | • LLW<br>• HLW<br>• TRU<br>• Solid<br>• Liquid | • MME 4341 Recycling Processes<br>• Higher yield, lower waste |
| • Long-Term Disposal | • TRU | • Engineering or Recycling @ LANL for or @ WIPP |

| **Classical Engineering** | | |
|---|---|---|
| **TOPIC** | **APPLICATION** | **LANL/UTEP Collaborations** |
| • Materials Selection | • Application of new materials | • MME 1405 Intro to Metal and Matls Eng<br>• MME 2303 Intro to Materials Science and Engineering |
| • Strength of Materials | • Application of new materials | • MME2434 Mechanics of Materials |

| **Manufacturing Technologies of Interest (Current Manufacturing)** | | |
|---|---|---|
| **TOPIC** | **APPLICATION** | **LANL/UTEP Collaborations** |
| • Foundry | • Optimize casting of Plutonium | • Simplified mold design<br>• Task 5<br>• Mold Coating<br>• Task 10<br>• Mold Materials<br>• Task 11 |
| • Purification<br>○ Electrorefining<br>○ Zone Refining | • High-purity plutonium<br>• Higher yield | • MM 4340 Mineral Processing |
| • Heat Treating | • Plutonium microstructure | • MM 3406 Nano Physical Metallurgy |
| • Machining | • High Precision Machining<br>• Micro-machining | • MM 3406 Nano Physical Meta |
| • Inspection | • CMM<br>• Optical | • MME4331 Non-Destructive Examination |
| • Radiography | • Digital Radiography<br>• Level of Definition | • MME4331 Non-Destructive Examination |
| • Welding | • Joining<br>• Laser Welding<br>• Solid State Bonding | • MM 4340 Material Joining Technologies |

| **Manufacturing Technologies of Interest (Future Manufacturing)** | | |
|---|---|---|
| **TOPIC** | **APPLICATION** | **LANL/UTEP Collaborations** |
| • Additive Manufacturing | • Resins<br>• Metals<br>• Refractory Metals | • MM 4404 Mat. Synthesis and Manufacturing<br>• Task 1<br>• Task 2<br>• Task 3 |
| • Radiation Protection | • New Materials | • Task 1 |
| • Chemical Compatibility | • Corrosion<br>• Chemical Damage | • Task 1 |

| **Analytical Technologies of Interest** | | |
|---|---|---|
| **TOPIC** | **APPLICATION** | **LANL/UTEP Collaborations** |
| • Microscopy<br>○ Light<br>○ SEM<br>○ TEM<br>○ Atomistic | | • MME 4315 Metallography and Micro Inter<br>• MM3413 Materials Characterization |

| | | |
|---|---|---|
| • Radiation Resistance | • Personnel protection<br>• Higher attenuation<br>• Less radiation damage | |
| • Composition<br>○ Alloy Levels<br>○ Impurities<br>○ Isotopics | • Non-destructive analytical chemistry methods | • MM 4321 Engineering Alloys |
| • Mechanical Testing<br>○ Quasi-Static<br>○ Kolsky<br>○ Gun<br>○ Explosive<br>○ U1a | • Constitutive Models<br>• Creep<br>• Temperature Cycling<br>• Dynamic Loading | • MME 2320 Introductory Mechanics<br>• MME 3407Mechanical Behavior of Materials<br>• New Kolsky System (B. Schuster)<br>• Task 6 |
| • Crystallographic Structures<br>○ X-Ray Diffraction<br>○ Neutron Diffraction<br>○ XAFS | | • MM 3406 Physical Metallurgy |
| • Corrosion<br>○ Gas-Metal Interactions<br>○ Storage | • Compatibility | • MME 4309 Corrosion<br>• Task 11 |
| • Phase Transformations | • Diffusion<br>• Changes in volume | • MM 3406 Physical Metallurgy<br>• MME 3308 Applied Chemical Thermodynamics<br>• Task 5 |
| • Alloying | • Alloy stability<br>• Optimize properties | • MME 3406 Physical Metallurgy<br>• MME 4321 Engineering Alloys |

| **Modeling** | | |
|---|---|---|
| **TOPIC** | **APPLICATION** | **LANL/UTEP Collaborations** |
| • Finite Element Modeling | • Foundry Optimization<br>○ Mold design<br>○ Mold filling<br>○ Solidification<br>○ Cooling rates<br>○ Grain Growth | • MME 1205 Computation/Graph in Material Science<br>• Task 5<br>• Task 8 |
| • Enterprise Modeling | • Big Picture Process Flow<br>○ Start to finish<br>○ Cradle to grave | • MME 4303 Metals Processing<br>• MME 4332 Root Cause Analyses |

# Metallurgical Topics that are Key to ALDWP Operations

| Topic | Application | CSM | UTEP |
|---|---|---|---|
| **Alloys** | Characterization of Pu Alloys | MTGN442, MTGN467 | MME3321, MME5321 |
| **Casting** | Casting Pu, U, Microstructure Development | MTGN457, MTGN468 | MME5321 |
| **Ceramics, Powder Processing** | Fabrication of Be, RTGs | MTGN310, MTGN345, MTGN465 | MME5311 |
| **Chemical Processing** | Electrorefining, Pyrometallurgy | MTGN334, MTGN432, MTGN535 | MME4303, MME5302 |
| **Composites** | Alternate Materials | MTGN565 | MME5313 |
| **Computational Methods** | Design of Molds, Stresses | MTGN467, MTGN473, MTGN536, MTGN573 | MME4419 |
| **Corrosion** | Gas-Metal interactions | MTGN451, MTGN551 | MME4309 |
| **Crystallography** | Distinction of Phases | Previously Taught | MME5401 |
| **Diffusion** | Heat Treating, Bonding | Previously Taught | MME5401 |
| **Electrochemistry** | Coating of Various Elements | MTGN431, MTGN437 | MME5342 |
| **ES&H** | Across the board | MTGN429, MTGN462, MTGN527, MTGN427, MTGN529 | NONE |
| **Fracture Mechanics, Failure Analysis** | Failure Modes | MTGN545, MTGN560 | MME4316, MME5353 |
| **Mechanical Metallurgy** | Dogbones, Strain Rate Effects, Rolling Forming , Forging | MTGN445, MTGN464, MTGN553, MTGN564 | MME2434, MME3407, MME5308 |

| Topic | Application | CSM | UTEP |
|---|---|---|---|
| **Microscopy** | Light, SEM, TEM | MTGN456, MTGN605 | MME4413, MME5245, MME5315, MME5401 |
| **Nano Materials** | Design and Fabrication of Nano-scale Materials | NONE | MME3406, MME4320 |
| **Nondestructive Analyses** | Certification of Components | NONE | MME5351 |
| **Nuclear Materials** | Actinide Science | MTGN593 | NONE |
| **Phase Transformations** | Casting, Heat Treating | MTGN281, MTGN548 | MMES304 |
| **Rate Processes, Transport** | Diffusion | MTGN556, MTGN631 | MME3306 |
| **Reactor Design** | Process equipment | MTGN461, MTGN539 | MME4404 |
| **Solidification** | Volume Changes, Microstructure | MTGN557 | MME4330 |
| **Statistical Design of Experiments** | Reduce number of experiments | MTGN350 | NONE |
| **Structure/Property Relations** | Effects of small changes | MTGN348 | MME5403, MME5404 |
| **Thermodynamics** | Fundamental Properties | MTGN352, MTGN531, MTGN555 | MME2303, MME2305, MME3308 |
| **Welding** | Welding, Soldering, | MTGN300, MTGN430, MTGN580 | MME4404, MME5350 |
| **X-Ray Diffraction** | Phases, Neutron Diffraction | Previously Taught | MME5401 |

For course descriptions see slide 8

# CSM Theses by RF Personnel

| Name | Type | Date | Title |
|---|---|---|---|
| **Zurey, Frank** | PhD (Olson) | 1977 | Stabilization of the plutonium delta phase in the plutonium-gallium-zirconium ternary phase equilibria system |
| **Rising, Tom** | PhD (Matlock) | 1978 | A thermal activation analysis of cyclic creep in Al-4.6% Mg |
| **Brown, Wendel** | PhD (Olson) | 1979 | The infiltration of silicon in silicon carbide-carbon compacts |
| **Erfurdt, Jack** | PhD (Olson) | 1979 | An investigation of the effect of iron content on the homogenization response of plutonium-1 wt % gallium alloy |
| **Lanning, Bruce** | MS (Averill) | 1981 | Development of a reference electrode for application in low to mid temperature aqueous solar energy environments |
| **Winkel, John** | MS (Olson) | 1982 | Compatibility of selected alloys with oxygen-contaminated liquid rubidium |
| **Perkins, Cathy** | MS (Matlock) | 1987 | Hot deformation behavior of a high nitrogen austentic stainless steel |
| **Olivas, Dave** | PhD (Olson) | 1989 | Fundamental approach to estimating bond integrity of solid state bonded dissimilar metals |
| **Swan, Kathy** | MS (Olson) | 1989 | Flexural strength and other aspects related to hydration of tricalcium silicate |
| **Gibbs, Frank** | PhD (Olson) | 1998 | Development of a Physical Metallurgy Surrogate for the Plutonium -1 Wt. PCT. Gallium Alloy |
| **Dooley, David** | PhD (Olson) | 2004 | Dependence of electronic properties on the degree of homogenization in cerium-lanthanum alloys |

Plutonium productionat Rocky Flats halted in 1989, the plant was formally shut down in 1992

# Questions

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# Course Descriptions

**METALLURGICAL AND MATERIALS ENGINEERING (CSM)**
**Metallurgy Courses Relevant to LANL**

**INTRODUCTORY CLASSES**

**MTGN202. ENGINEERED MATERIALS. 3.0 Semester Hrs.**
Equivalent with SYGN202,
(I, II, S) Introduction to the Metallurgical and Materials Engineering paradigm: processing, structure, and properties. The course will relate technologically significant processing procedures to resultant structures. The material structure will be examined to determine its effect upon material properties. Students will study materials engineering methodologies and learn terminology. 3 hours lecture; 3 semester hours. Prerequisite: CHGN121, MATH112, and PHGN100.

**MTGN211. STRUCTURE OF MATERIALS. 3.0 Semester Hrs.**
(II) Principles of atomic bonding, crystallography, and amorphous structures. ii) Symmetry relationships to material properties. iii) Atomic structure determination through diffraction techniques. Prerequisite: MTGN202. Corequisite: PHGN200. 3 hours lecture; 3 semester hours.

**MTGN442. ENGINEERING ALLOYS. 3.0 Semester Hrs.**
This course is intended to be an important component of the physical metallurgy sequence, to reinforce and integrate principles from earlier courses, and enhance the breadth and depth of understanding of concepts in a wide variety of alloy systems. Metallic systems considered include iron and steels, copper, aluminum, titanium, superalloys, etc. Phase stability, microstructural evolution and structure/property relationships are emphasized. Offered every year. Prerequisite: MTGN348.

**Metallurgical and Materials Engineering (MME) Undergraduate Catalogue (UTEP)**

**INTRODUCTORY CLASSES**

MME 1301 **Introduction to Metallurgical and Materials Engineering Design (3-0)** This course combination MME 1301/MME 1101 will introduce the student to effective procedures for solving simple metallurgical and materials engineering and design problems, using mathematics, computers, basic measuring systems and devices, computational tools, and statistical concepts. The course will also introduce the student to the metallurgical and materials engineering profession, including the role and responsibilities of the engineer in today's society. The laboratory portion is MME 1101. Prerequisite (may be taken concurrently): English 1311 and Math 1411.

MME 2303 **Introduction to Materials Science and Engineering (3-0)** Introduction to properties of engineering materials and relationships to their structure, behavior, and processing. Materials testing and measurement of properties. Selection of materials for engineering applications, considering interrelationships between structure, properties, processing, and performance. Prerequisite: Chemistry 1305, with a grade of "C" or better.

## PHYSICAL METALLURGY

**MTGN251. METALLURGICAL AND MATERIALS THERMODYNAMICS. 3.0 Semester Hrs.**
(I) Applications of thermodynamics in extractive and physical metallurgy and materials science. Thermodynamics of solutions including solution models and thermodynamic properties of alloys and slags. Reaction equilibria with examples in alloy systems and slags. Phase stability analysis. Thermodynamic properties of binary alloys in the solid state, defect equilibrium, and interactions. Prerequisites: MATH112, CHGN122 or CHGN125, and PHGN100. 3 hours lecture; 3 semester hours.

**MTGN281. INTRODUCTION TO PHASE EQUILIBRIA IN MATERIALS SYSTEMS. 2.0 Semester Hrs.**
Review of the concepts of chemical equilibrium and derivation of the Gibbs phase rule. Use of thermodynamic principles for constructing and interpreting one, two and three component phase equilibrium diagrams. Application to alloy and ceramic materials systems. Emphasis on the evolution of phases and their amounts and the resulting microstructural development.
Prerequisite: MTGN202, MTGN251.

**MTGN348. MICROSTRUCTURAL DEVELOPMENT. 3.0 Semester Hrs.**
An introduction to the relationships between microstructure and properties of materials, with emphasis on metallic and ceramic systems; Fundamentals of imperfections in crystalline materials on material behavior; recrystallization and grain growth; strengthening mechanisms: microstructural refinement, solid solution strengthening, precipitation strengthening, cold work; and phase transformations.
Prerequisite: MTGN211, MTGN251. Co-requisite: MTGN281, MTGN348L.

**MTGN352. METALLURGICAL AND MATERIALS KINETICS. 3.0 Semester Hrs.**
Introduction to reaction kinetics: chemical kinetics, atomic and molecular diffusion, surface thermodynamics and kinetics of interfaces and nucleation-and-growth. Applications to materials processing and performance aspects associated with gas/solid reactions, precipitation and dissolution behavior, oxidation and corrosion, purification of semiconductors, carburizing of steel, formation of p-n junctions and other important materials systems. Prerequisite: MTGN272. Co-requisite: MTGN251.

**MTGN457. SOLIDIFICATION. 3.0 Semester Hrs.**
This course is intended to provide students with a working understanding of solidification processing of metals relevant to crystal growth, casting, welding, and additive manufacturing. Topics in the course are: 1) thermodynamics, 2) nucleation, 3) heat transfer, 4) interface stability and solidification morphology, 5) dendritic growth, 6) microsegregation, and 7) columnar vs equiaxed dendritic growth.
Prerequisite: MTGN348.

**MTGN461. TRANSPORT PHENOMENA AND REACTOR DESIGN FOR METALLURGICAL AND MATERIALS ENGINEERS. 3.0 Semester Hrs.**
(I) Introduction to the conserved-quantities: momentum, heat, and mass transfer, and application of chemical kinetics to elementary reactor-design. Examples from materials processing and process metallurgy. Molecular transport properties: viscosity, thermal conductivity, and mass diffusivity of materials encountered during processing operations. Uni-directional transport: problem formulation based on the required balance of the conserved- quantity applied to a control-volume. Prediction of velocity, temperature and concentration profiles. Equations of change: continuity, motion, and energy. Transport with two independent variables (unsteady-state behavior). Interphase transport: dimensionless correlations friction factor, heat, and mass transfer coefficients. Elementary concepts of radiation heat-transfer. Flow behavior in packed beds. Design equations for: continuous- flow/batch

## PHYSICAL METALLURGY

MME 2305 **Material and Energy Balance (3-0)** Introduction to process variables, stoichiometry, materials balance, first law of thermodynamics, and energy balance applied to materials systems. Prerequisite: Chemistry 1305 or 1306 and Math 2313, each with a grade of "C" or better.

MME 3306 **Rate Processes in Materials System (3-0)** Introduction to reaction kinetics, fluid flow, and heat transfer applied to materials systems. Prerequisite: MME 1101, MME 1301, CHEM 1306, and MATH 2326 or MATH 3326, each with a grade of "C" or better, and Junior standing.

MME 3308 **Applied Chemical Thermodynamics (3-0)** First, second, and third law of thermodynamics applied to materials systems. Topics include thermochemistry, chemical equilibria, phase equilibria, solutions, activity, and electrochemical potential. Prerequisite: MME 2305 with a grade of "C" or better and Junior standing.

MME 3309 **Introduction to Electronic Materials Science (3-0)** Basic theory of the electrical, semiconductor, magnetic, optical, and superconductor properties of materials. Application and fabrication of selected materials. Prerequisite: PHYS 2421 with a grade of "C" or better.

MME 3406 **Nanofunctional Physical Metallurgy (4-0)** The underlying principles of physical metallurgy dealing with the structure property relationships will be covered. Topics include crystal structures, nano, micro, and macro defects, solid solutions, precipitation hardening, diffusion and phase equilibria including nanophases, deformation and annealing, nucleation and growth, solidification, and nanophases affecting properties. Restricted to major: MME.Prerequisite: MME 2303 with a grade of "C" or better and junior standing.

MME 4330 **Solidification Processes (3-0)** Fundamentals of solidification in processes commonly found in manufacturing. The course will cover the principles involved in metal casting, welding, brazing, soldering, and plastic injection molding. Prerequisite: MME 2303 with a grade of "C" or better.

**MME 5403. Adv Concepts in Matls Sci Engr.**
Advanced Concepts in Materials Science and Engineering (4-0) A blend of contemporary solid state physics and chemistry emphasizing structure and properties and including processing (synthesis) and performance, illustrated by various classes of materials: structural, electronic, magnetic, photonic, and superconducting. Fundamental issues and applications will include: crystal structure and crystal chemistry; disorder/order imperfections; phase equilibria, phase diagrams, phase transformaion; reaction rates, kinetics, thermodynamics; microstructures in processing and performance; materials design/materials by design. Prerequisites: MME 2306, MME 2308, and MME 3406.

**MME 5304. Phase Transformations & Micros.**
Phase Transforming and Microstructures (3-0) The theory of the nucleation and growth kinetics of solid materials, solid-solid transformations and mechanisms. Rate processes, decomposition and ordering reactions and microstructures. Diffusionless transformations, eutectoid, and martensitic transformations are covered along with associated microstructural morphologies and property/ performance control by microstructure control in materials. Prerequisite: MME 3406 and 3407, or equivalent, MME 5401, or department appro

reactors with uniform dispersion and plug flow reactors. Digital computer methods for the design of metallurgical systems. Prerequisite: MATH225, MTGN334, and MTGN352. 3 hours lecture; 3 semester hours.

**MTGN531. THERMODYNAMICS OF METALLURGICAL AND MATERIALS PROCESSING. 3.0 Semester Hrs.**
(I) Application of thermodynamics to the processing of metals and materials, with emphasis on the use of thermodynamics in the development and optimization of processing systems. Focus areas will include entropy and enthalpy, reaction equilibrium, solution thermodynamics, methods for analysis and correlation of thermodynamics data, thermodynamic analysis of phase diagrams, thermodynamics of surfaces, thermodynamics of defect structures, and irreversible thermodynamics. Attention will be given to experimental methods for the measurement of thermodynamic quantities. Prerequisite: MTGN351. 3 hours lecture; 3 semester hours.

**MTGN548. TRANSFORMATIONS IN METALS. 3.0 Semester Hrs.**
(I) Surface and interfacial phenomena, order of transformation, grain growth, recovery, recrystallization, solidification, phase transformation in solids, precipitation hardening, spinoidal decomposition, martensitic transformation, gas metal reactions. Prerequisite: none. 3 hours lecture; 3 semester hours. (Fall of odd years only.).

**MTGN555. SOLID STATE THERMODYNAMICS. 3.0 Semester Hrs.**
(I) Thermodynamics applied to solid state reactions, binary and ternary phase diagrams, point, line and planar defects, interfaces, and electrochemical concepts. Prerequisite: none. 3 hours lecture; 3 semester hours.

**MTGN556. TRANSPORT IN SOLIDS. 3.0 Semester Hrs.**
(I) Thermal and electrical conductivity. Solid state diffusion in metals and metal systems. Kinetics of metallurgical reactions in the solid state. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of even years only.).

**MTGN557. SOLIDIFICATION. 3.0 Semester Hrs.**
(I) Heat flow and fluid flow in solidification, thermodynamics of solidification, nucleation and interface kinetics, grain refining, crystal and grain growth, constitutional supercooling, eutectic growth, solidification of castings and ingots, segregation, and porosity. Prerequisite: none. 3 hours lecture; 3 semester hours. (Fall of odd years only.).

**MTGN593. NUCLEAR MATERIALS SCIENCE AND ENGINEERING. 3.0 Semester Hrs.**
(I) Introduction to the physical metallurgy of nuclear materials, including the nuclear, physical, thermal, and mechanical properties for nuclear materials, the physical and mechanical processing of nuclear alloys, the effect of nuclear and thermal environments on structural reactor materials and the selection of nuclear and reactor structural materials are described. Selected topics include ceramic science of ceramic nuclear material, ceramic processing of ceramic fuel, nuclear reaction with structural materials, radiation interactions with materials, the aging of nuclear materials, cladding, corrosion and the manufacturing of fuels elements. Relevant issues in the modern fuel cycle will also be introduced including nuclear safety, reactor decommissioning, and environmental impacts. Prerequisites: Graduate or Senior in good-standing. 3 hours lecture, 3 semester hours. (Fall of even years only.).

**MTGN631. TRANSPORT PHENOMENA IN METALLURGICAL AND MATERIALS SYSTEMS. 3.0 Semester Hrs.**
Physical principles of mass, momentum, and energy transport. Application to the analysis of extraction metallurgy and other physicochemical processes. Prerequisite: MATH225 and MTGN461 or equivalent. 3 hours lecture; 3 semester hours.

PHYSICAL METALLURGY

**MME 5403. Adv Concepts in Matls Sci Engr.**
Advanced Concepts in Materials Science and Engineering (4-0) A blend of contemporary solid state physics and chemistry emphasizing structure and properties and including processing (synthesis) and performance, illustrated by various classes of materials: structural, electronic, magnetic, photonic, and superconducting. Fundamental issues and applications will include: crystal structure and crystal chemistry; disorder/order imperfections; phase equilibria, phase diagrams, phase transformaion; reaction rates, kinetics, thermodynamics; microstructures in processing and performance; materials design/materials by design. Prerequisites: MME 2306, MME 2308, and MME 3406.

## MECHANICAL METALLURGY

**MTGN445. MECHANICAL PROPERTIES OF MATERIALS. 3.0 Semester Hrs.**
(I) Mechanical properties and relationships. Plastic deformation of crystalline materials. Relationships of microstructures to mechanical strength. Fracture, creep, and fatigue. 3 hours lecture, 3 semester hours. Prerequisite: MTGN348 and CEEN241 and CEEN311. Co-requisite: MTGN445L.

**MTGN464. FORGING AND FORMING. 2.0 Semester Hrs.**
Introduction to plasticity, survey and analysis of working operations including forging, extrusion, rolling, wire drawing and sheet-metal forming. Metallurgical structure evolution during working. Prerequisite: MTGN281 or CEEN311, MTGN348. Co-requisite: MTGN464L.

**MTGN545. FATIGUE AND FRACTURE. 3.0 Semester Hrs.**
(I) Basic fracture mechanics as applied to engineering materials, S-N curves, the Goodman diagram, stress concentrations, residual stress effects, effect of material properties on mechanisms of crack propagation. Prerequisite: none. 3 hours lecture; 3 semester hours. (Fall of odd years only.).

**MTGN553. STRENGTHENING MECHANISMS. 3.0 Semester Hrs.**
(II) Strain hardening in polycrystalline materials, dislocation inter actions, effect of grain boundaries on strength, solid solution hardening, martensitic transformations, precipitation hardening, point defects. Prerequisite: MTGN543 or concurrent enrollment. 3 hours lecture;3 semester hours. (Spring of even years only.).

**MTGN564. ADVANCED FORGING AND FORMING. 3.0 Semester Hrs.**
(II) Overview of plasticity. Examination and Analysis of working operations of forging, extrusion, rolling, wire drawing and sheet metal forming. Metallurgical structure evolution during working. Laboratory experiments involving metal forming processes. Prerequisites: MTGN445/MLGN505, 2 hours lecture; 3 hours lab, 3 semester hours.

## MECHANICAL METALLURGY

MME 2434 **Mechanics of Materials (3-3)** A first course in Newtonian mechanics using vectors. Equilibrium of particles and rigid bodies, forces in space, centroids, moments of inertia, study of stress and strain; use of stress-load equations to determine the state of stress in specific structural elements; study of combined stresses.
Prerequisite: Math 1411 with a grade of "C" or better.

MME 3407 **Mechanical Behavior of Materials (4-3)** The microstructure-property relationships will be emphasized in this course. The deformation processes for metals, ceramics, polymers, and composite materials will be analyzed in terms of current theories and models. The topics include twinning, martensite, fracture, dislocation theory, plastic deformation, creep, fatigue, strengthening mechanisms, and mechanical testing. Prerequisite: MME 2303 and MME 3406, each with a grade of "C" or better.

**MME 5308. Mechanical Behavior of Matls.**
Mechanical Behavior of Materials (3-0) The underlying principles of elastic and plastic deformation of metals, ceramics, polymers, and composite materials will be developed. Topics include dislocation theory, slip, twinning, microstructures, high and low temperature deformation behavior (tensile properties, creep and fatigue) of crystal line and amorphous materials. Offered in alternate years.

**MME 5353. Fracture Mechanics.**
Fracture Mechanics: Mechanisms of fracture for brittle and ductile materials using linear elastic and elastic-plastic fracture mechanics. ASTM standard fracture testing, numerical methods, and creep, fatigue, and dynamic fractures of metallic and non-metallic materials.

## MICROSCOPY

**MTGN456. ELECTRON MICROSCOPY. 2.0 Semester Hrs.**
(I, II, S) Introduction to electron optics and the design and application of transmission and scanning electron microscopes. Interpretation of images produced by various contrast mechanisms. Electron diffraction analysis and the indexing of electron diffraction patterns. 2 hours lecture; 2 semester hours. Prerequisite: MTGN211. Co-requisite: MTGN456L.

**MTGN605. ADVANCED TRANSMISSION ELECTRON MICROSCOPY. 2.0 Semester Hrs.**
Introduction to transmission electron microscopy techniques and their application to materials characterization. Topics include electron optics, electron-specimen interactions, imaging, diffraction, contrast mechanisms, defect analyses, compositional measurements using energy dispersive x-ray spectroscopy and energy loss spectroscopy, scanning transmission electron microscopy, high angle annular dark field imaging, energy filtered TEM and high resolution phase contrast imaging. Prerequisite: MTGN 505. Co-requisite; MTGN 605L. 2 hours lecture, 2 semester hours.

**MTGN656. ADVANCED ELECTRON MICROSCOPY. 2.0 Semester Hrs.**
Advanced introduction to electron optics and the design and application of transmission and scanning electron microscopes. Interpretation of images produced by various contrast mechanisms. Electron diffraction analysis and the indexing of electron diffraction patterns. Co-requisite: MTGN656L.

## MICROSCOPY

MME 4413 **Structural Characterization (4-3)** The application of modern instrumentation and techniques to structural characterization problems. Both theory and operation will be stressed. X-Ray analysis, electron microscopy (TEM-SEM), and electron probe analysis will be included. Prerequisite: MME 3407 with a grade of "C" or better or department approval.

**MME 5245. Electron Microscopy Appl.**
Course will provide detailed instruction and hands on experience in the use of electron microscopy instrumentation (such as TEM, STEM, SEM/EDS). Aspects related to interpretation of contrast mechanisms, general instrument operation, benefits and disadvantages of different types of instruments as well as sample preparation will be covered. Keywords: materials characterization, microstructure, electronic.

**MME 5315. Metallography and Micro Inter..**
Metallography and Microstructure Interpretation: Metallographic sample preparation and microstructural characterization for various metals, alloys and/or material systems. Use of tools necessary for analysis including sectioning, mounting, polishing and etching using standard metallographic procedures. Metallographic samples prepared in class will be evaluated using stereomicroscopy, optical and electron microcopy for microstructural interpretation. Introduction to chemical analysis using optical emission spectroscopy and X-ray fluorescence for positive material identification.

**MME 5401. Microstruc & Microchem Charac.**
Microstructural and Microchemical Characterization of Materials (3-3) An interdisciplinary approach to the theory and applications of techniques for characterizing chemical (microchemical) and microstructural features of solid materials. Tecniques that will be stressed include X-ray diffraction, optical metallography, scanning and tranmission electron microscopy (emphasizing analytical transmission electron microscopy), electron probe microanalysis, and surface and near surface surface microanalysis (Auger electron spectroscopy, ESCA, SIMS, etc.). Sample preparation techniques will be covered and students will be encouraged to examine materials which may have some application to their research problems. Keywords: characterization, electrons, atomic, structure, electronic

## COMPUTATIONAL METHODS

**MTGN350. STATISTICAL PROCESS CONTROL AND DESIGN OF EXPERIMENTS. 3.0 Semester Hrs.**
Introduction to statistical process control, process capability analysis and experimental design techniques. Statistical process control theory and techniques developed and applied to control charts for variables and attributes involved in process control and evaluation. Process capability concepts developed and applied to the evaluation of manufacturing processes. Theory of designed experiments developed and applied to full factorial experiments, fractional factorial experiments, and multilevel experiments. Analysis of designed experiments by graphical and statistical techniques. Introduction to computer software for statistical process control and for the design and analysis of experiments.

**MTGN467. MATERIALS DESIGN: SYNTHESIS, CHARACTERIZATION AND SELECTION. 2.0 Semester Hrs.**
(I) Application of fundamental materials engineering principles to the design of systems, processes, and/or components for extraction, synthesis, operation and/or selection of materials in open-ended projects with realistic constraints. Project topics range from processes used for metallurgical processing and extraction to design and development of emergent materials to process/component analysis and (re)design. Chemical and microstructural characterization and property measurements provide the basis for linking synthesis to application and/or process to product. Selection criteria tied to specific requirements drive design under realistic constraints that include an appropriate mix of technical, economic, safety, and other considerations. Activities are carried out in teams in collaboration with project sponsors/clients. 1 hour lecture, 3 hours lab; 2 semester hours.
Prerequisite: MTGN350, MTGN352, and MTGN348 or MTGN345.

**MTGN468. MATERIALS DESIGN: SYNTHESIS, CHARACTERIZATION AND SELECTION. 2.0 Semester Hrs.**
(II) Application of fundamental materials engineering principles to the design of systems, processes, and/or components for extraction, synthesis, operation and/or selection of materials in open-ended projects with realistic constraints. Project topics range from processes used for metallurgical processing and extraction to design and development of emergent materials to process/component analysis and (re)design. Chemical and microstructural characterization and property measurements provide the basis for linking synthesis to application and/or process to product. Selection criteria tied to specific requirements drive design under realistic constraints that include an appropriate mix of technical, economic, safety, and other considerations. Activities are carried out in teams in collaboration with project sponsors/clients. Prerequisite: MTGN352. Corequisites: MTGN348, MTGN334. 1 hour lecture, 3 hours lab; 2 semester hours.

**MTGN473. COMPUTATIONAL MATERIALS. 3.0 Semester Hrs.**
(II) Computational Materials is a course designed as an introduction to computational approaches used in modern materials science and engineering, and to provide the hands-on experience in using massively parallel supercomputers and executing popular materials software packages. The main goal is to provide exposure to students to the growing and highly interdisciplinary field of computational materials science and engineering, through a combination of lectures, hands-on exercises and a series of specifically designed projects. The course is organized to cover different length scales including: atomistic (electronic structure) calculations, molecular dynamics, and phase equilibria modeling. The emerging trends in data driven materials discovery and design are also covered. Particular emphasis is placed on the validation of computational results and recent trends in integrating theory, computations and experiment. 3 hours lecture; 3 semester hours.

## COMPUTATIONAL METHODS

MME 4419 **Metallurgical and Materials Engineering Design and Practice (3-3)** Introduction to creative industrial problem-solving and the design process in materials engineering. Topics include material and process selection, project planning and resource management, economic decision making in terms of cost evaluation and profitability, and optimization methods. Weekly discussions explore issues of professionalism including engineering ethics, public safety and environmental concerns in design, codes, and standards, etc. Student design teams define and investigate problems in metallurgical processing, materials selection and evaluation, quality control, etc. Design project teams make written proposals and oral progress reports, as well as a final written report and presentation. Laboratory time is devoted to design projects.  Prerequisite: MME 3407, with a grade of "C" or better, MME 4303.

## COMPUTATIONAL METHODS

**MTGN536. OPTIMIZATION AND CONTROL OF METALLURGICAL SYSTEMS. 3.0 Semester Hrs.**
Application of modern optimization and control theory to the analysis of specific systems in extractive metallurgy and mineral processing. Mathematical modeling, linear control analysis, dynamic response, and indirect optimum seeking techniques applied to the process analysis of grinding, screening, filtration, leaching, precipitation of metals from solution, and blast furnace reduction of metals. Prerequisite: none. 3 hours lecture; 3 semester hours.

**MTGN539. PRINCIPLES OF MATERIALS PROCESSING REACTOR DESIGN. 3.0 Semester Hrs.**
(II) Review of reactor types and idealized design equations for isothermal conditions. Residence time functions for nonreacting and reacting species and its relevance to process control. Selection of reactor type for a given application. Reversible and irreversible reactions in CSTR?s under nonisothermal conditions. Heat and mass transfer considerations and kinetics of gas-solid reactions applied to fluo-solids type reactors. Reactions in packed beds. Scale up and design of experiments. Brief introduction into drying, crystallization, and bacterial processes. Examples will be taken from current metallurgical practice. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

**MTGN573. COMPUTATIONAL MATERIALS. 3.0 Semester Hrs.**
(II) Computational Materials is a course designed as an introduction to computational approaches and codes used in modern materials science and engineering, and to provide the hands?on experience in using massively parallel supercomputers and popular materials software packages. The main goal is to provide exposure to students to the growing and highly interdisciplinary field of computational materials science and engineering, through a combination of lectures, hands-on exercises and a series of specifically designed projects. The course is organized to cover different length scales including: atomistic (electronic structure) calculations, molecular dynamics, and phase equilibria modeling. The emerging trends in data driven materials discovery and design are also covered. Particular emphasis is placed on the validation of computational results and recent trends in integrating theory, computations and experiment. Graduate students are expected to successfully complete 4 projects while the undergraduate students are required to finish 3 out of 4 projects. 3 hours lecture; 3 semester hours.

**MTGN300. FOUNDRY METALLURGY. 2.0 Semester Hrs.**
(II) Design and metallurgical aspects of casting, patterns, molding materials and processes, solidification processes, risers and gating concepts, casting defects and inspection, melting practice, cast alloy selection. Corequisite: MTGN300L. 2 hours lecture; 2 semester hours.

**MTGN430. PHYSICAL CHEMISTRY OF IRON AND STEELMAKING. 3.0 Semester Hrs.**
Physical chemistry principles of blast furnace and direct reduction production of iron and refining of iron to steel. Discussion of raw materials, productivity, impurity removal, deoxidation, alloy additions, and ladle metallurgy. Prerequisite: MTGN334, MTGN251.

**MTGN475. METALLURGY OF WELDING. 2.0 Semester Hrs.**
Introduction to welding processes; thermal aspects; selection of filler metals; stresses; stress relief and annealing; pre- and postweld heat treating; weld defects; welding ferrous and nonferrous alloys; weld metal phase transformations; metallurgical evaluation of resulting weld microstructures and properties; and welding tests. Offered every year. Prerequisite: MTGN348. Co-requisite: MTGN475L.

**MTGN530. ADVANCED IRON AND STEELMAKING. 3.0 Semester Hrs.**
(I) Physicochemical principles of gas-slag-metal reactions applied to the reduction of iron ore concentrates and to the refining of liquid iron to steel. The role of these reactions in reactor design?blast furnace and direct iron smelting furnace, pneumatic steelmaking furnace, refining slags, deoxidation and degassing, ladle metallurgy, alloying, and continuous casting of steel. Prerequisite: DCGN209 or MTGN351. 3 hours lecture; 3 semester hours. (Fall of even years only.).

**MTGN549. CURRENT DEVELOPMENTS IN FERROUS ALLOYS. 3.0 Semester Hrs.**
(I) Development and review of solid state transformations and strengthening mechanisms in ferrous alloys. Application of these principles to the development of new alloys and processes such as high strength low alloy steels, high temperature alloys, maraging steels, and case hardening processes. Prerequisite: MTGN348. 3 hours lecture; 3 semester hours.

**MTGN560. ANALYSIS OF METALLURGICAL FAILURES. 3.0 Semester Hrs.**
(II) Applications of the principles of physical and mechanical metallurgy to the analysis of metallurgical failures. Nondestructive testing. Fractography. Case study analysis. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

**MTGN580. ADVANCED WELDING METALLURGY. 3.0 Semester Hrs.**
(II) Weldability of high strength steels, high alloys, and light metals; Welding defects; Phase transformations in weldments; Thermal experience in weldments; Pre- and Post-weld heat treatment; Heat affected zone formation, microstructure, and properties; Consumables development. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

FABRICATION METALLURGY

MME 3321 **Engineering Alloys (3-0)** The study of the selection and specification of engineering alloys for the use in industrial applications. Topics related to ferrous and non-ferrous metals in the cast, wrought, powder, and particle state will be covered. Prerequisite: MME 3407 with a grade of "C" or better or department approval.

MME 4304 **Printable Materials (3-0)** This course deals with various aspects of nano size particles in conjuction with printing processes to form layered materials for flexible electronics, sensors, RFIDs, and medical devices. Major issues that arise in direct writing processes: ink-jet, micro dispensing deposition write; R2R systems, printable components and processes, emphasizing the fundamental physical chemistry, colloidal stability; general modeling and mathematical concepts, and analysis and simulation tools required for existing or future printable applications. Prerequisites: CHEM 1306 and PHYS 2421 with a grade of C or better; department approval also required. Restricted to majors of MME and Senior standing.

MME 4316 **Failure Analysis (3-0)** The mechanisms of materials failure, failure analysis techniques, and non-destructive testing methods are discussed with emphasis on analysis and interpretation of case studies.
Prerequisite: MME 2303 and MME 2434, each with a grade of "C" or better, and Junior standing.

MME 4320 **Nanomaterials and Nanostructures (3-0)** Topics will include zero-dimensional nanostructures (including nanoparticles), one and two-dimensional nanostructures (nanowires, nanorods, nano-thin films), nanotubes (especially carbon nanotubes), nanomaterials fabrication and applications, and nanostructure characterization. Prerequisite: MME 2303, with a grade of "C" or better.

MME 4404 **Materials Processing (3-3)** Materials and processes in soldering, brazing, glass and ceramic production, powder metallurgy, surface modification, vapor deposition, fabrication of patterned multi-layers, solidification, etc. Analysis using material and energy balance, fluid flow, heat transfer, kinetics, and thermodynamics. Applications: crystal growth, ceramic/metal joining, glass/metal seals, varistors, ferrites, ceramic capacitors, coatings, CMOS transistors and IC's advanced metal casting, printed wiring boards, and sensors. Prerequisite: MME 4303 with a grade of "C" or better.

**MME 5313. Advanced Matrls & Composites.**
Advanced Materials and Composites (3-0) Properties and structures of composite materials and design of composite systems to yield desired combinations of properties. Metal, ceramic, and polymer composite systems as well as high-performance alloy system or microcomposites. Applications of materials and composite fundamentals to manufacturing and processing. Offered in alternate years. Prerequisites: MME 5401 and 5403 or department approval.

**MME 5314. Polymer Engineering.**
Polymer Engineering: The course provides a basic introduction to the field of polymer science. Basic concepts of organic chemistry address typical polymerization and copolymerization reactions. The characterization of polymer molecules include discussions of thermodynamic solutions, solubility parameters, colligative properties and scanning electron microscopy. Concepts on the structure and properties of bulk polymers emphasize its relationship to molecular characteristics and manufacturing processes.

## FABRICATION METALLURGY

**MME 5321. Engineering Alloys.**
Engineering Alloys: The study of the selection and specification of engineering alloys for use in industrial applications. Topics related to ferrous and nonferrous metals in the cast, wrought, powder and particulate state will be covered. Mill test reports (MTR) and how to interpret them as well as interpreting compliance with various specification entities to include ASTM, API, ABS, etc. are inherent.

**MME 5350. Material Joining Technologies.**
Material Joining Technologies: Fundamentals of materials joining theory and application. A variety of technologies will be covered, to include: welding, brazing, soldering, adhesives, etc. for metals, ceramics, polymers, composites and electronic materials. Emphasis will be on both the theoretical principles of each process and practical aspects of the technique and/or equipment.

**MME 5351. Non-Destructive Examination.**
Non-Destructive Examination: Introduction and theory of ultrasonic testing, such as phased array and shear wave techniques, dye penetration inspection, interpretation of radiographs, wet/dry magnetic particle inspection, chemical analysis using X-ray fluorescence and in-situ metallography techniques (replication).

**MME 5352. Root Cause Analysis.**
Root Cause Analysis: Using analytical techniques to determine underlying causes and causal factors related to materials, component and systemic problems. Analytical tools and techniques will be used to identify problems and track data used to determine the root and proximate cause and to implement corrective actions.

**MTGN429. METALLURGICAL ENVIRONMENT. 3.0 Semester Hrs.**
(I) Examination of the interface between metallurgical process engineering and environmental engineering. Wastes, effluents and their point sources in metallurgical processes such as mineral concentration, value extraction and process metallurgy are studied in context. Fundamentals of metallurgical unit operations and unit processes with those applicable to waste and effluent control, disposal and materials recycling are covered. Engineering design and engineering cost components are also included for selected examples. Fundamentals and applications receive equal coverage. Prerequisites: MTGN334. 3 hours lecture; 3 semester hours.

**MTGN462. SOLID WASTE MINIMIZATION AND RECYCLING. 3.0 Semester Hrs.**
(I) This course will examine, using case studies, how industry applies engineering principles to minimize waste formation and to meet solid waste recycling challenges. Both proven and emerging solutions to solid waste environmental problems, especially those associated with metals, will be discussed. Prerequisites: CEEN301, CEEN302, and CHGN403. 3 hours lecture; 3 semester hours.

**MTGN527. SOLID WASTE MINIMIZATION AND RECYCLING. 3.0 Semester Hrs.**
(II) Industrial case-studies, on the application of engineering principles to minimize waste formation and to meet solid waste recycling challenges. Proven and emerging solutions to solid waste environmental problems, especially those associated with metals. Prerequisites: ESGN500 and ESGN504. 3 hours lecture; 3 semester hours.

**MTGN529. METALLURGICAL ENVIRONMENT. 3.0 Semester Hrs.**
(I) Effluents, wastes, and their point sources associated with metallurgical processes, such as mineral concentration and values extraction?providing for an interface between metallurgical process engineering and the environmental engineering areas. Fundamentals of metallurgical unit operations and unit processes, applied to waste and effluents control, recycling, and waste disposal. Examples which incorporate engineering design and cost components are included. Prerequisites: MTGN334. 3 hours lecture; 3 semester hours.

ES&H

**No Classes in the UTEP MME Curriculum**

**MTGN334. CHEMICAL PROCESSING OF MATERIALS. 3.0 Semester Hrs.**
Development and application of fundamental principles related to the processing of metals and materials by thermochemical, aqueous, and fused salt electrochemical/chemical routes. The course material is presented within the framework of a formalism that examines the physical chemistry, thermodynamics, reaction mechanisms and kinetics inherent to a wide selection of chemical processing systems. The general formalism provides for a transferable knowledge-base to other systems not specifically covered in the course. Prerequisite: MTGN272, MTGN351, and CEEN267 or EDNS251 or EDNS261 or EDNS262 or EDNS264 or EDNS269. Co-requisite: MTGN334L.

**MTGN431. HYDRO- AND ELECTRO-METALLURGY. 3.0 Semester Hrs.**
(I, II, S) Physicochemical principles associated with the extraction and refining of metals by hydro- and electrometallurgical techniques. Discussion of unit processes in hydrometallurgy, electrowinning, and electrorefining. Analysis of integrated flowsheets for the recovery of nonferrous metals. Offered every other year. 3 hours lecture; 3 semester hours. Prerequisite: MTGN334, MTGN352, and MTGN251. Co-requisite: MTGN461.

**MTGN432. PYROMETALLURGY. 3.0 Semester Hrs.**
(II) Extraction and refining of metals including emerging practices. Modifications driven by environmental regulations and by energy minimization. Analysis and design of processes and the impact of economic constraints. Prerequisite: MTGN334. 3 hours lecture; 3 semester hours.

**MTGN451. CORROSION ENGINEERING. 3.0 Semester Hrs.**
Principles of electrochemistry. Corrosion mechanisms. Methods of corrosion control including cathodic and anodic protection and coatings. Examples of corrosion problems and solutions from various industries. Prerequisite: MTGN251.

**MTGN523. APPLIED SURFACE AND SOLUTION CHEMISTRY. 3.0 Semester Hrs.**
(II) Solution and surface chemistry of importance in mineral and metallurgical operations. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

**MTGN526. GEL SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.**
An introduction to the science and technology of particulate and polymeric gels, emphasizing inorganic systems. Interparticle forces. Aggregation, network formation, percolation, and the gel transition. Gel structure, rheology, and mechanical properties. Application to solid-liquid separation operations (filtration, centrifugation, sedimentation) and to ceramics processing. Prerequisite: Graduate Status. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

**MTGN528. EXTRACTIVE METALLURGY OF COPPER, GOLD AND SILVER. 3.0 Semester Hrs.**
Practical applications of fundamentals of chemical-processing-of-materials to the extraction of gold, silver and copper. Topics covered include: History; Ore deposits and mineralogy; Process Selection; Hydrometallurgy and leaching; Oxidation pretreatment; Purification and recovery; Refinement; Waste treatment; and Industrial examples. Prerequisites: Graduate or Senior in good-standing. 3 hours lecture, 3 semester hours.

EXTRACTIVE METALLURGY

MME 4303 **Metals Processing (3-0)** Analysis of the unit operations involved in metal and mineral production using the principles of material and energy balance, fluid flow, heat transfer, reaction kinetics, and thermodynamics. Survey of processing operations for specific metals such as copper, iron, aluminum, magnesium, titanium, and uranium. Prerequisite: MME 3306, MME3308, each with a grade of "C" or better.

MME 4309 **Corrosion (3-0)** Application of electrochemistry and engineering principles to the corrosion, passivity, and protection of metals and alloys. Prerequisite: MME 2303 with a grade of "C" or better or department approval.

**MME 5302. Matls Extrac, Synth, & Process.**
Materials Extraction, Synthesis, and Processing (3-0) Thermodynamic, thermochemical, electrochemical kinetic, and phase equilibrium fundamentals and fundamental structures and properties of materials applied to examples of ferrous and non-ferrous extraction and processing. Examples include copper extraction, refinement, processing, alloying and performance; iron and steel making and iron alloy processing, metal and ceramic powder processing, and contemporary materials synthesis and processing. Keywords: Materials chemistry, electrochemistry, hydrometallurgy, pyrometallurgy.

**MME 5342. Hydrometallurgy.**
Hydrometallurgy: The study of metal extraction process in aqueous solutions from ore or concentrates.

# EXTRACTIVE METALLURGY

**MTGN530. ADVANCED IRON AND STEELMAKING. 3.0 Semester Hrs.**
(I) Physicochemical principles of gas-slag-metal reactions applied to the reduction of iron ore concentrates and to the refining of liquid iron to steel. The role of these reactions in reactor design?blast furnace and direct iron smelting furnace, pneumatic steelmaking furnace, refining slags, deoxidation and degassing, ladle metallurgy, alloying, and continuous casting of steel. Prerequisite: DCGN209 or MTGN351. 3 hours lecture; 3 semester hours. (Fall of even years only.).

**MTGN532. PARTICULATE MATERIAL PROCESSING I - COMMINUTION AND PHYSICAL SEPARATIONS. 3.0 Semester Hrs.**
An introduction to the fundamental principles and design criteria for the selection and use of standard mineral processing unit operations in comminution and physical separation. Topics covered include: crushing (jaw, cone, gyratory), grinding (ball, pebble, rod, SAG, HPGR), screening, thickening, sedimentation, filtration and hydrocyclones. Two standard mineral processing plant-design simulation software (MinOCad and JK SimMet) are used in the course. Prerequisites: Graduate or Senior in good-standing. 3 hours lecture, 3 semester hours.

**MTGN533. PARTICULATE MATERIAL PROCESSING II - APPLIED SEPARATIONS. 3.0 Semester Hrs.**
An introduction to the fundamental principles and design criteria for the selection and use of standard mineral processing unit operations in applied separations. Topics covered include: photometric ore sorting, magnetic separation, dense media separation, gravity separation, electrostatic separation and flotation (surface chemistry, reagents selection, laboratory testing procedures, design and simulation). Two standard mineral processing plant-design simulation software (MinOCad and JK SimMet) are used in the course. Graduate or Senior in good- standing. 3 hours lecture, 3 semester hours.

**MTGN535. PYROMETALLURGICAL PROCESSES. 3.0 Semester Hrs.**
(II) Detailed study of a selected few processes, illustrating the application of the principles of physical chemistry (both thermodynamics and kinetics) and chemical engineering (heat and mass transfer, fluid flow, plant design, fuel technology, etc.) to process development. Prerequisite: none. 3 hours lecture; 3 semester hours.

**MTGN537. ELECTROMETALLURGY. 3.0 Semester Hrs.**
(II) Electrochemical nature of metallurgical processes. Kinetics of electrode reactions. Electrochemical oxidation and reduction. Complex electrode reactions. Mixed potential systems. Cell design and optimization of electrometallurgical processes. Batteries and fuel cells. Some aspects of corrosion. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of even years only.).

**MTGN538. HYDROMETALLURGY. 3.0 Semester Hrs.**
(II) Kinetics of liquid-solid reactions. Theory of uniformly accessible surfaces. Hydrometallurgy of sulfide and oxides. Cementation and hydrogen reduction. Ion exchange and solvent extraction. Physicochemical phenomena at high pressures. Microbiological metallurgy. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

**MTGN551. ADVANCED CORROSION ENGINEERING. 3.0 Semester Hrs.**
(I) Advanced topics in corrosion engineering. Case studies and industrial application. Special forms of corrosion. Advanced measurement techniques. Prerequisite: MTGN451. 3 hours lecture; 3 semester hours. (Fall of even years only.).

CERAMICS

**MTGN310. POWDER PROCESSING AND FORMING. 2.0 Semester Hrs.**
Fabrication of components from powder-based feedstocks is central to both ceramic and metallurgical engineering, and the concepts of powder processing apply to industries as diverse as mining, food products, paints, and many more. This course covers the handling, measurement, and application of powdered feedstocks to the formation of green bodies (i.e., powder compacts) using both wet and dry methods. Particular attention is paid to the importance of powder characteristics, green density, impurities and other defects in these initial stages to the final density, microstructure and overall properties of the subsequent part, whether the parts are sintered or consolidated in another way such as laser powder bed fusion (LPBF). Prerequisite: MTGN202, MTGN251. Co-requisite: MTGN310L.

**MTGN314. PROPERTIES AND PROCESSING OF CERAMICS. 2.0 Semester Hrs.**
(I) Application of engineering principles and fundamental structure-processing-property relationship to inorganic non-metallic materials. Emergence of macroscopic characteristics and functional properties from bonding, structure, symmetry, and defects. Applications of basic thermodynamic and kinetic principles to powder-based processing. 2 hours lecture; 2 semester hours. Co-requisite: MTGN314L, MTGN202, and MTGN251.

**MTGN345. SINTERING OF CERAMICS. 1.0 Semester Hr.**
This is the laboratory course for MTGN345. This course covers the fundamentals and applications of sintering based processes in ceramic engineering. It includes solid-state, liquid phase, reactive and vapor phase sintering and covers densifying and non-densifying mechanisms as well as microstructure development for bulk, coatings, and additively manufactured parts. The course covers technologies used in the processing of ceramics. Prerequisite: MTGN310, MTGN352, MTGN281. Co-requisite: MTGN345.

**MTGN414. ADVANCED PROCESSING AND SINTERING OF CERAMICS. 3.0 Semester Hrs.**
(II) Principles of ceramics processing and the relationship between processing and microstructure, with a focus on advanced microstructural control using thermal and athermal energy input in single and multiphase systems. Principles will be illustrated using case studies on specific ceramic materials. A project to design a ceramic fabrication process is required. Prerequisite: MTGN314. 3 hours lecture; 3 semester hours.

**MTGN410. THERMAL PROPERTIES OF CERAMICS. 3.0 Semester Hrs.**

This course covers the fundamentals and applications of ceramic materials? responses to thermal energy. Thermal responses are fundamentally borne from atomic scale processes which will be covered in detail. Particular attention is paid to thermal conduction, melting, thermally induced strain, thermomechanical stresses, and engineering microstructures to obtain specific thermal performances. Prerequisite: MTGN315, MTGN310.

**MTGN465. MECHANICAL PROPERTIES OF CERAMICS. 3.0 Semester Hrs.**
Mechanical properties of ceramics and ceramic-based composites; brittle fracture of solids; toughening mechanisms in composites; fatigue, high-temperature mechanical behavior, including fracture and creep deformation. Offered every year. Prerequisite: MTGN310, CEEN241, CEEN311. Co-requisite: MTGN465L.

**MTGN565. MECHANICAL PROPERTIES OF CERAMICS AND COMPOSITES. 3.0 Semester Hrs.**
(I) Mechanical properties of ceramics and ceramic-based composites; brittle fracture of solids; toughening mechanisms in composites; fatigue, high temperature mechanical behavior, including fracture, creep deformation. Prerequisites: MTGN445 or MLGN505. 3 hours lecture; 3 semester hours. (Fall of even years only.).

**CERAMICS**

**MME 5311. Ceramics.**
Understanding the development, utilization and control of ceramic materials properties based on microstructure