DOE/ID/13429

Cast Metal Coalition Research and Development Closeout Report

Final Report – 07/15/1996 – 07/31/2000

D. Allen

August 2000

Work Performed Under Contract No. DE-FC07-96ID13429

For
U.S. Department of Energy
Assistant Secretary for
Energy Research
Washington, DC

By
Cast Metal Coalition
North Charleston, SC

DISCLAIMER

DOE/ID/13429

CAST METAL COALITION RESEARCH AND DEVELOPMENT CLOSEOUT REPORT

FINAL REPORT
07/15/1996 – 07/31/2000

D. Allen

August 2000

Work Performed Under Contract No. DE-FC07-96ID13429

Prepared for the
U.S. Department of Energy
Assistant Secretary for
Energy Research
Washington, DC

Prepared by
Cast Metal Coalition
North Charleston, SC

CMC R&D CLOSEOUT REPORT

CONTRACT # DE-FC07-96ID13429

JULY 15, 1996 THROUGH JULY 31, 2000

- CANMET/Metals Technology Labs
- Carnegie Mellon University
- Case Western Reserve University
- Climax Research Services
- Colorado School of Mines
- L.E. Griffith & Associates
- Idaho National Engineering Lab
- Iowa State University
- Materials Properties Council
- Nupro Corporation
- Oak Ridge National Lab
- Ohio State University
- Pennsylvannia State University
- University of Alabama
- University of Alabama - Birmingham
- University of Iowa
- University of Michigan
- University of Missouri - Rolla
- University of Northern Iowa
- University of Tennessee
- University of Wisconsin - Milwaukee
- Worcester Polytechnic Institute

CAST METAL COALITION

5300 International Blvd.
North Charleston, SC 29418
Phone: 843-760-3210
Fax: 843-767-3368
Http://cmc.aticorp.org/

This is the closeout report for the Cast Metal Coalition's 1996-2000 R&D partnership with the US Department of Energy.

Competitive collaboration is a proven model of success. The Cast Metal Coalition has been a results-oriented program demonstrating the technical, industrial and national value of competitive collaborators working with the US Department of Energy.

CMC's research and development program began in 1996 and since that time has involved more then 22 research providers and universities, and over 149 industrial partners to deliver technology and value to its stakeholders. At its conclusion, this program has borne out several important strengths in collaboration:

1. Industrial partners influence and outreach are vital to successful government / industry programs.
2. Balance of control and independence in managing consortia is critical to successful collaboration.
3. Technology Transfer requires commitment of commercial entities to ultimately be successful.

Much has been learned and applied as a result of CMC. Our technology summaries shown in the following sections reviews the R&D highlights of our 29 projects. Program technical committee minutes and program status reports are likewise included. The Cast Metal Coalition is pleased to have had the opportunity to partner with the U.S. Department of Energy in this important national initiative.

Dennis Allen
Program Manager

CMC Research and Development Close-Out

August 8, 2000

Cast Particulate Metal Matrix Components

This study provides quantitative correlation to help establish industry procedures for mechanical testing and structural characterization of discontinuously reinforced aluminum (DRA) particulate silicon carbide. In addition, the variability of mechanical properties as a function of casting procedures, microstructural features will result in a handbook of best practices to minimize property variation and maximize the mean value. Materials suppliers, casting producers, and U.S Automotive Materials Partnership (USAMP) have teamed as mutually benefiting stake holders in this effort. Tensile properties from foundry produced were completed in Phase I. Stepped Castings are being prepared in Phase II to investigate the effect of cooling rate on the tensile and fatigue properties.

The purchase of a new image analyzer will provide state of the art detailed correlation between structure, volume percent silicon carbide and mechanical properties of aluminum-silicon carbide composite alloys. A commercial fatigue testing laboratory will of a limited number of test bars in to validate existing data. Ultrasonic velocities (both longitudinal and transverse) were measured for a statistically significant number of samples to develop correlation between these a non-destructive test parameters, mechanical properties and volume % silicon carbide. Stepped castings are being cast at Eck Inc. for Phase Two evaluation of aluminum-silicon carbide test bars. A paper was presented at the American Foundry Society Casting Congress and will be published in *AFS Transactions*.

Clean, Machinable, Thin-Walled Gray & Ductile Iron

There is a growing demand in work cells and on transfer lines for consistent high-speed machinability of cast iron. Higher speeds increase throughput and minimize part cost. However, machining at high speeds requires parts with uniform microstructures, consistent properties, and a minimum volume fraction of abrasive inclusions. Fundamental understanding is sought to learn how to modify the foundry process to produce castings to meet all specified mechanical properties while substantially improving machining behavior. Machining data on gray and ductile iron quantifies the effects of pearlite, ferrite, carbides, intermetallic compounds, and oxides. A technique was developed to accurately measure tool wear as a function of metallurgical variables and machining conditions. The improved technique provides a rate of tool wear and volume of metal removed as a function of casting variables. This is the first time a precise and repeatable technique is available to quantify factors that affect tool-wear rate. Undissolved silicon, presumably from post inoculants, appears to significantly degrade the machinability of iron castings.

Clean Metal Casting

This project has developed technology for clean aluminum processing that is capable of consistently providing melt cleanliness level that is fit for a given application. The program has four technical tasks: Development of melt cleanliness assessment technology, development of melt contamination avoidance technology, development of high temperature phase separation technology, and establishment of a correlation between the level of melt cleanliness and as-cast mechanical properties. Significant technology was transferred to the industrial sector. Within the context of the first task, a standardized Reduced Pressure Test that has been developed and endorsed by AFS as a recommended practice. In addition, within the context of the first task, a melt cleanliness sensor based on the principles of electromagnetic separation was developed. An industrial partner is commercializing the sensor. Within the context of the second task, environmentally friendly fluxes that do not contain fluorine were developed. An industrial partner will soon commercialize these fluxes. Within the context of the third task, the process of rotary degassing was modeled and the model predictions verified with experimental data. This model is being used to optimize the performance of commercial industrial rotary degassers.

Control Ladle Temperature

The capability to measure ladle temperature has been demonstrated. The development and acquisition of additional thermocouples is expected to demonstrate the stratification of ladle temperature and ways of homogenizing the temperature.

Cupola Neural Network Model & Feedback Control
This project uses the principles of Integrated Intelligent Industrial Process Sensing and Control (I3PSC) to measure and describe the cupola melting process in greater detail than has previously been possible. It integrates a number of process models-- numerical, neural network, and expert knowledge base-- with a suite of sensors, including software and self-verifying sensors, in an expandable way, and with real data from previous operations. This information can be presented to cupola operators or engineering staff in a flexible, understandable way that allows them to make decisions effectively. These decisions may be at high levels, such as choosing operating regimes and evaluating the economics of charge materials or cupola design changes, or they may be at a lower level, yielding a more accurate description of cupola operation from moment to moment to aid tactical decision making. The availability of information at all these levels aids in the development and implementation of more effective automatic control algorithms. Work on this project is a joint effort of Tennessee Technological University in Cookeville, Utah State University in Logan, and the Idaho National Engineering and Environmental Laboratory.

Design Parameters - Lead Free Copper Alloys
An impediment to the acceptance of the permanent mold casting of copper alloys is lack of adequate data on permanent mold design and mechanical properties. This is especially in applications where their inherent corrosion resistance, high thermal and electrical conductivity are superior to other engineering alloys.

The mechanical, fracture toughness, impact, and fatigue properties of 13 copper alloys (aluminum bronzes [C95200, C95300, C95400, C95500, and C95800], yellow brass [C85800], high strength yellow brass [C86300], silicon brass [C87500], manganese yellow brasses [C99700 and C99750] and the high copper alloys [C80100, C81500, and C82500] have been established. For the first time, a comprehensive data on mechanical, impact, fatigue, fracture toughness, as well as wear and corrosion properties (selected alloys from the group) is available for these alloys.

The mechanical, fracture toughness, impact, and fatigue properties of these alloys are strongly dependent on the chemical composition. The nominal composition does not always provide the best combination of strength and ductility. To achieve optimum properties for a given application, a narrower composition range than in the current specifications should be targeted, especially for those elements that have been shown to have the greatest effect on properties. The mechanical properties were incorporated by CDA in their publications, and will be proposed for ASTM specifications.

Develop Database Design Rules-Creep Res
This work has demonstrated the clear difference between microalloyed and non-microalloyed creep resistant materials. This difference is on average 30% greater for the microalloyed materials. The work is a basis for the development of design rules for API. the metallographic work has suggested a way to develop a screening test for the micro alloyed materials.

Die Deflection & Distortion Modeling
The outcome of this project is a computer model, which simulates the deflection of die casting dies under applied and thermal loads. Interaction from the die casting machine is also taken into consideration. Although the model requires further development and further validation before it becomes commercial, the deflection modeling has shown that, for a given total die plus insert thickness, thinner inserts (more die steel behind the insert) seem to yield lower separations. The model shows that the better the die support system is, the lower the deflections are. Achieving a straight through load path and utilizing thicker, more rigid platens are better from a deflection perspective. Also the model has indicated that a mid to high die position on a horizontal machine is generally better and that the cover half is more sensitive than the ejector half. These are highly useful and significant findings.

Energy Assessment
The outcome of this project is the energy use portion of the NADCA Energy Saving Manual. The manual shows how to analyze the energy usage in the process and non-process areas throughout a die casting facility and indicates some of the most energy-efficient practices. A spreadsheet program is included to assist in calculating the amount of energy usage.

Fast Shot Transition Point

A designed experiment approach was developed using computer simulation to evaluate the effect of cavity pre-fill, and the interaction of cavity pre-fill with transition time, pre-fill velocity, and geometry. Both cavity pre-fill and fast shot transition time were shown to have significant effects on air entrapment, which causes gas porosity in the cast part. This work has shown very good correlation of computer flow modeling to the water analog modeling. The evaluation of various shot sleeve fill percentages and fast shot transition point on the amount of air entrapment for specific die cavity geometries and gate sizes has provided useful information on how to approach die cavity filling for minimizing casting quality problems associated with gas porosity.

Ferrite Determination

The development of a method to determine ferrite levels in duplex stainless steel castings has been successful. The development of standards for this measurement is continuing to allow manufacturers and users to use non destructive methods instead of the time consuming and expensive microstructural methods.

Flow of Steel in Gating Systems

The use of shrouds has shown major steps forward in the reduction of inclusions in large castings. Work on smaller castings through studies of the gating systems is continuing. The work on smaller castings is demonstrating the limits of numerical modeling of fluid flow.

Heat Transfer and Casting Distortion

An investigation to determine the interfacial heat transfer coefficients during both resin-bonded and green sand casting of aluminum (A356) was conducted. To obtain these results, instrumented plate castings were poured, and temperature data collected from these castings were used to solve the inverse heat conduction problem. A special formulation of the inverse heat conduction problem was derived to deal with moisture in the case of green sand. The magnitude and variation of the heat transfer coefficient during solidification for resin-bonded sand molds was determined for three different section sizes. The results indicate that the heat transfer coefficients during resin-bonded sand casting of A356 aluminum are on the order of 600 W/m^2-K. The interfacial heat transfer coefficient is approximately constant during the solidification process for sections of 0.50-inch, or greater, in thickness. For thinner sections, the heat transfer coefficient varies through most of the solidification process, and can double in magnitude. The investigation focused on thinner sections in the case of green sand. For 0.25-inch thick sections the heat transfer coefficient was on the order of 400-500 W/m^2-K.

Heat Transfer - Perm Mold Al. Alloys

- A framework was developed for a Heat Transfer Coefficient Evaluator software. The goal is that commercial software houses will incorporate this module in their solidification modeling packages. It would provide the solidification modeler with sound estimates of heat transfer coefficients on various surfaces of a solidifying casting produced by any of the myriad of casting processes.
- A commercial test casting of hockey puck-like shape (a gear blank) produced by vertical squeeze casting was verified to be accurately modeled. The secondary dendrite arm spacing was correlated with a specific cooling rate for a modified A356 alloy. During the solidification process, the interfacial heat transfer coefficient is relatively uniform over the casting and on reaching a critical solidification pressure, the heat transfer coefficient is about 4700 W/m^2 K. The literature indicates that even higher coefficients can be reached at higher pressures and in the absence of mold coating.
- A relatively large axis symmetric shape (wheel blank) was modeled. It is cast in a coated, permanent mold imbedded with thermocouples to permit the radially symmetrical casting to be segmented into sections with different heat transfer coefficients in each area. This work is continuing and includes metallographic examination of casting sections, as well as an examination of steel samples coated with the materials used in low pressure permanent mold casting at a commercial operation.

High Speed Milling & Pulsed ECM

The major outcome of this project is a set of suggested guidelines for the high speed machining of die steels in the fully hardened condition. Several factors were taken into consideration such as milling insert geometry, insert coating, tool path, tool head rigidity, feed rate and depth of cut. The guidelines state that tool paths that maintain a constant chip thickness (or as close to constant as possible) are required for good performance and for minimizing surface damage. In the study, it was shown that inserts with flat rake faces and multi-layer PVD coatings perform the best when cutting H-13 above 45 HRC. Among the various outer-layer coatings tested, TiN and TiCN performed best. These items are also encompassed in the guidelines.

Impurity Limits in Aluminum Bronzes

The effects of impurity elements on the mechanical properties, heat treatment and weldability of aluminum bronze alloys were studied.. The alloys selected for the study were Al Bronze (C95400) and Ni-Al Bronze (C95800). The impurity elements investigated are lead, zinc, tin, bismuth, selenium, chromium, silicon, and beryllium. These elements are added in one, two and three element combinations.

The UTS and yield strength of alloy C95800 was not reduced by the addition of impurity elements. On the contrary, the results indicate that both in as-cast and heat-treated conditions the elements added were found to improve the strength. However, the ductility of the alloy was found to be adversely affected by the impurity element addition. The work on the weldability of alloy C95800 indicated that only lead and bismuth were detrimental and caused cracking in the heat affected zone. Combining the results from the mechanical properties and weldability, the new limits for the impurity elements in alloy C95800 could be specified as follows:

Lead	0.01%	Zinc	1.00%
Tin	0.10%	Bismuth	0.03%
Selenium	0.035%	Silicon	0.10%
Chromium	0.10%	Beryllium	0.10%

The results from the work on alloy C95400 indicate that more emphasis should be placed on the maximum aluminum content. The existing standards call for a nominal aluminum content of 10.8%, which was found to be too high to achieve the required ductility. The optimum aluminum content was found to be 10.6%. In the case of impurity elements investigated only two elements lead and bismuth were found to be detrimental to properties after heat treatment. Each of these elements should be controlled below 0.02% since they cause severe embrittlement.

Inoculation Studies

Several melts of A356 alloy have been carried out. Currently, tests are being conducted based on a statistical design of experiments (DOE). Based on industrial data indicating that the residual titanium level in the aluminum A356 alloy has a strong effort on grain refinement, all tests are being conducted on special melts containing high and low levels of residual titanium. The strontium level is being kept constant for each melt. Three grain refiner master alloys are being tested: 3Ti-1B, 1.6Ti-1.4B, and 10.6Sr-2.1B. For the strontium containing master alloy, a Sr-free version of A356 alloy is being used. For each experiment, a spectrometer sample, grain size sample, thermal analysis sample, and two permanent mold tensile bars have been obtained. The analysis will determine the efficiency of each grain refiner master alloy and provide the basis for industrial trials.

Lost Foam Process Development: Phase III

- Fatigue properties of a class 35 gray iron, a 100-70-03 ductile iron, and a 356 aluminum were determined.
- A procedure was developed to measure pattern densities in various locations. This procedure has been adopted in many foundries as a quality control tool for pattern quality.
- The root causes of laps and folds in both iron and aluminum castings has been identified as either (a) oxide folds or (b) folds containing pattern pyrolysis by-products trapped between converging metal fronts. This discovery has directed research toward polymers such as PAC that decompose to produce a smaller liquid fraction. Although copolymers and PMMA degrade to produce less liquid than polystyrene (EPS), the increased cost of these polymers has limited their use.
- The root cause of several casting dimensional problems determined to be excessive sand expansion during pouring and cooling of the casting. The use of low expansion sands in the lost foam casting process has significantly improved dimensional accuracy. Synthetic sands, with rounded shapes and

better flowability, have also provided improved dimensional accuracy by requiring less compaction energy.

- The role of gating in the lost foam casting process has been evaluated. It was found that the heat transfer from the metal to the pattern, coupled with the coating/sand permeability, controls the filling process rather than the gate size. Unfortunately, the gating system also serves to stiffen and strengthen the pattern cluster for handling and dipping, but the multiple gates aggravate converging metal fronts and lap/fold formation.

Mechanical Properties of Squeeze & Semi-Solid Cast A356
A database of properties was established for specimens removed from production castings. Tensile, hardness, microstructure and fatigue data was generated for squeeze cast 356-T61, A356-T61 and B356-T61. Tensile, hardness and microstructure data was generated for semi-solid metal cast A357-T61 and A357-T62. The resultant data was compiled into tables and graphs, which were used to expand the publication entitled "NADCA Product Specification Standards for Die Castings Produced by the Semi-Solid and Squeeze Cast Processes".

Die casters and designers now have available, a database of realistic mechanical properties currently being achieved by commercial squeeze and SSM producers. This allows the designer to consider these new casting technologies for components that require higher strength and integrity. In addition, the die caster can now refer to the product standards book to determine whether these new technologies can meet specific customer requirements and, where appropriate, recommend these new technologies for specific applications.

Microstructural Evaluation
Work is continuing to examine the differences in behavior of cast and wrought product forms. Current work is examining the effect of inclusions on pitting resistance.

Part Distortion: Prediction and Control
The main outcome of this project is a model that predicts part distortion using cavity shape at the point of ejection as the initial part shape. Although more considerations need to be added to have a complete predictive model and more validation is required, factors such as thermal expansion and pressure deflection of dies, restraint caused by the die, ejection forces and thermal contraction of the part have been taken into consideration. The information provided by the model allows for better dimensional control of die castings.

Plasma Refining Process Development
The results of this work show that further development is necessary in what promises to be an alternative to AOD refining in small vessels.

Process Parameters for Copper

- Thermal shock resistance of various materials (e.g.. cast iron, tool steel, Cu-Be, Ni-Be, Nickel Aluminide) used to make the molds for copper alloy permanent mold casting process was evaluated and ranked.

- The grain refinement behavior of permanent mold cast silicon brass, silicon bronze, and lead-free red brass was studied. The grain refiners investigated are Cu-B, zirconium, and a commercial grain refiner FKM 2000. Zirconium was effective for silicon brass and silicon bronze. Lead-free red brass was partially grain refined by boron.

- The effect of minor alloy additions such as Al, Mg, and Pb on the fluidity of tin bronze, silicon brass and silicon bronze was investigated. Only aluminum improved the casting fluidity.

- Water modeling studies were carried out to evaluate the fluid flow in selected permanent molds. The turbulent flow, jetting, and air entrapment were predicted. These problems were shown to be reduced by altering the gating and pouring practices.

- Aluminum is known to improve the fluidity of various alloys including leaded yellow brass, silicon brass and silicon bronze in permanent molds. Efforts were made to predict the microstructural changes and enhanced fluidity using mathematical modeling. The study shows that aluminum changes the surface tension of copper and this in turn modifies the nucleation and growth behavior of dendrites during solidification. The dendrite morphology changes from interlocking to fine feathery structure. These changes were shown to enhance the fluidity.
- A new low melting copper alloy suitable for permanent mold casting was developed. This alloy contains zinc (20-25%), nickel (4-5%), phosphorous (3-5%) and aluminum (0.5%) as the major alloy additions. The low melting temperature of the alloy makes it attractive to permanent molds since it reduces thermal shock. The alloy posses good casting characteristics (fluidity and hot tearing resistance) as well as good tensile strength and corrosion resistance comparable to yellow brass and found to be pressure tight. However, this alloy has moderate ductility and poor machinability.
- Zinc in yellow brass, produces zinc oxide that deposits on the permanent molds (due to the low vapor pressure). This deposit not only reduces casting fluidity but also produces poor surface quality. The deposit is usually removed by dipping the molds in water/graphite slurry and in extreme cases has to be removed physically. In an attempt to minimize the oxide deposition, the effect of aluminum and magnesium additions on the zinc oxide formation and deposition was studied. It was found that a combination of Al and Mg reduced the zinc oxide deposition significantly.

Residual Stress and Softening Effects on Die Life
This study assessed the contribution of softening and residual stress to the thermal fatigue failure mechanism of die casting dies. Based on this study, it appears that the loss of surface hardness plays a larger role in thermal fatigue cracking than the build-up of residual stresses. A major outcome of the project is the suggestion that surface hardness be monitored and action taken to reclaim the surface hardness when the surface hardness drops to a Rockwell C level in the approximate upper 30's. The intent is to extend die life by taking remedial action prior to the occurrence of thermal fatigue cracking (heat checking) while maximizing time between maintenance/repair cycles.

A number of instruments were evaluated for in-sité measurement of hardness in dies. The instrument of choice to measure the surface hardness is the Krautkramer MIC10 with a 5Kg indenter probe.

Semi-Solid Metal Consortium
The outcome of this project, to date, is fourfold. First, a better understanding of the relationship between SSM billet quality and the casting processing behavior has been achieved. A qualitative analysis method for raw billet material that will be induction heated has been subsequently developed. Second, a better understanding of the microstructure evolution as a result of processing has been achieved and this information is presently being pursued to develop a mathematical model for microstructure. Third, a database of experimentally measured yield stress values/ rheological properties of SSM material has been established. Fourth, a computer model to predict die filling with SSM slurry has been developed. The model takes the complex rheology of SSM material into consideration and uses conservation equations and the Herschel-Bulkey fluid flow model.

Steel Macro-Inclusions Atlas/Elimination
This project developed a World Wide Web site for a steel inclusion atlas that suggests potential solutions to the occurrence of intermetallic and nonmetallic inclusions in steel castings. Macro-inclusions generated in melting by induction electric furnaces, arc furnaces, and vacuum furnaces were documented to develop a non-metallic inclusion atlas. Samples from a previous DOE study were expanded to include thirteen additional foundries. Furnace melting practices, and metal handling practices which contribute to the creation of non-metallic inclusions are placed as an atlas on a world wide web site. The URL (http://neon.mems.cum.edu/afs) address contains a section on inclusion stability diagrams that helps the foundry engineer to identify processing options to minimize the formation of offending intermetallic phases.

Thin Section Steel Castings
The major physical effects on the ability to produce thin castings has been determined. The ability to making thinner castings than originally consider practical has been demonstrated reducing wall thickness in trial castings from 6mm to 4mm.

Wear Analysis of Foundry Tooling Materials
The wearability of different tooling materials, both metallic and non-metallic, in actual on the floor foundry tests were conducted at ten foundries equipped with DisaMatic molding equipment. DisaMatics were chosen because their rapid cyclic rate could achieve the large number of cycles within a relatively short time. Measurements of a test pattern specifically designed for this project were taken using a single Coordinate Measurement Machine (CMM) at CMI International to improve gauge R&R. However, visual observations of the test pattern found that some of the most significant wear occurred in areas not included in the surveyed area surveyed by the CMM.

Materials chosen with Tooling Division steering committee input included the very popular polyurethane elastomer tooling materials. They are compared against Class 40 Gray Iron (a very common tooling material), D2 Tool Steel (becoming more common), 303-304 Stainless Steel (used extensively in high production facilities), and 6061 Aluminum (used extensively in short and medium production foundries).

As expected the 303-304 Stainless Steel material displayed less wear than the other materials in this study. However, the a less common D2 Tool Steel, including the Wear Coated, displayed comparable numbers to Stainless Steel and may be more appropriate for some tooling applications. The polyurethane elastomer tooling materials did not perform in general as well as the metals which was expected. However, some dimensions at certain locations on the test pattern showed comparable wear to the metals.

Wear coating of the test specimens did not appear to enhance the overall wearability of the test pattern especially pertaining to the D2 Steels. On some locations of the test pattern, the wear coating protected the material early in the trials. However, some of the dimensional changes on Wear Coated 6061 aluminum did display an improvement over the non-coated specimens.

Yield Improvement
The new feeding distances which are based on cast plates and numerical models show that the existing rules are conservative. A new handbook of rules will be published containing the new rules. The rules will be presented in a format that will make them useable by those foundries with numerical models and those foundries which rely on a manual approach to risering. The case studies have shown foundries how their current yield and feeding problems may be overcome. Trials with unconventional approaches to feeding have demonstrated significant improvements in yield.

DOE F 4600.6
(10-94)
Replaces EIA-459F
All Other Editions Are Obsolete

OMB Control No.
1910-0400

U.S. Department of Energy
FEDERAL ASSISTANCE PROGRAM/PROJECT STATUS REPORT

OMB Burden Disclosure Statement

1. Program/Project Identification No.	2. Program/Project Title	3. Reporting Period
DE-FC07-96ID13429	Cast Metal Coalition	4/1/00 through ~~6/30/00~~

4. Name and Address	5. Program/Project Start Date
ATI 5300 International Blvd. North Charleston, SC 29418	7/15/96
	6. Completion Date 7/15/00

7. Approach Changes

No approach changes.

8. Performance Variances, Accomplishments, or Problems

None

9. Open Items

...king on Contract Close-Out

10. Status Assessment and Forecast

Project Close-Out

| No Deviation from Plan is Expected

11. Description of Attachments

DOE Milestone Log and Milestone Plan

| None

12. Signature of Recipient and Date	13. Signature of U.S. Department of Energy (DOE) Reviewing Representative and Date
T. Yale Culler 8/1/00	

U.S. DEPARTI[illegible]IT OF ENERGY
FEDERAL ASSISTAN[illegible]E MILESTONE PLAN

1. Program/Project Identification No.
DE-FC07-96ID13429

2. Program/Project Title
Cast Metal Coalition

3. Performer (Name, Address)
ATI
5300 International Boulevard
North Charleston, SC 29418

4. Program/Project Start Date
7/15/1996

5. Program/Project Completion Date
7/14/2000

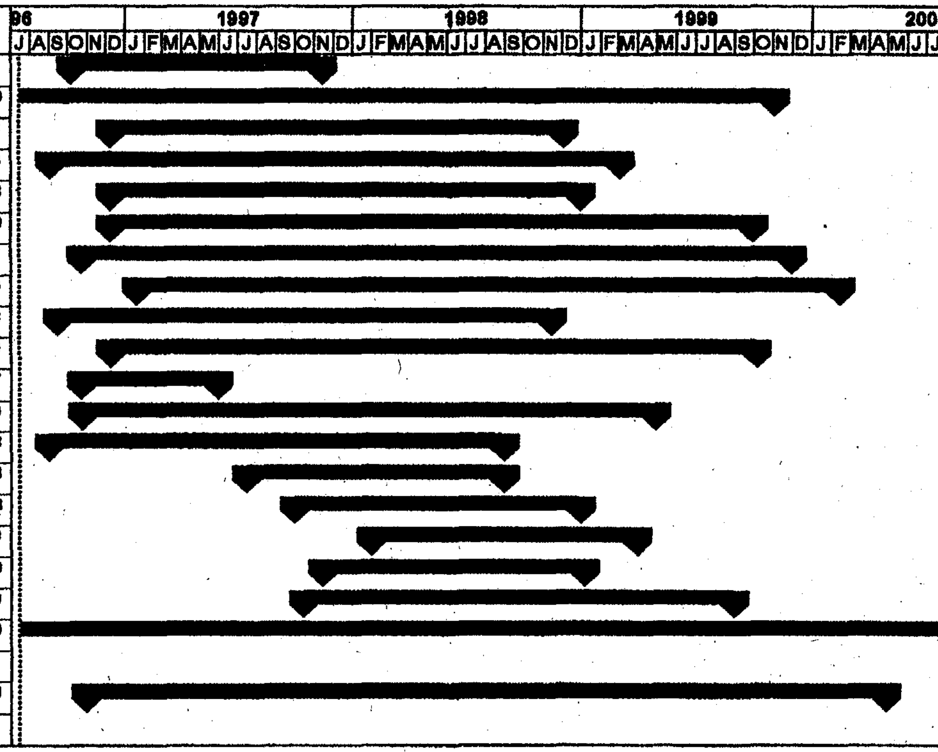
6. ID #

7. Planning Category (Work Breakdown Structure Tasks)

8. Program/Project Duration

9. Comments (Notes, Name of Performer)

WBS	Task Name	%	Finish
1.1	Energy Assessment, L.E.Griffith & Associates	100%	Fri 11/14/97
1.2	Yield Improvement, UI	100%	Thu 11/4/99
1.3	Late-Stream Inoculation Studies, CRS	100%	Fri 12/4/98
1.4	High Speed Milling and Pulsed ECM, OSU	100%	Wed 3/3/99
1.5	Process Parameters, CANMET/MTL	100%	Thu 12/31/98
1.6	Design Parameters, CANMET/MTL	100%	Thu 9/30/99
1.7	Fast Shot Transition Point, OSU	100%	Tue 11/30/99
1.8	Development of Database Design Rules, MPC	100%	Tue 2/15/00
1.9	Wear Analysis, UNI	100%	Sun 11/15/98
1.10	Residual Stress & Softening on Die Life, CWRU	100%	Wed 10/6/99
1.11	Microstructural Evaluation, UT	100%	Fri 5/30/97
1.12	Impurity Limits in Aluminum Bronzes, CANMET/N	100%	Fri 4/30/99
1.13	Steel Macro-Inclusions Atlas/Elimination, CMU	100%	Mon 8/31/98
1.14	Semi-Solid Metals Processing Consortium, WPI	100%	Mon 8/31/98
1.15	Properties of Squeeze & Semi-Solid Cast A356, CW	100%	Thu 12/31/98
1.16	Ferrite Determination, UT	100%	Wed 3/31/99
1.17	Cast Particulate Metal Matrix Composites, UWM	100%	Wed 1/6/99
1.18	Plasma Refining Process Development, Nupro Cor	100%	Tue 8/31/99
3.0	Collaboration	100%	Mon 7/31/00
	Kickoff	100%	Mon 7/15/96
3.1	Quarterly Reports	100%	Fri 4/28/00
3.2	End-of-Program Final Review	100%	Mon 7/31/00



10. Remarks

11. Signature of Recipient

12. Signature of U.S. Department of Energy (DOE) Reviewing Representative and Date

DOE F 4600.3A
(03-94)

U.S. DEPARTMENT OF ENERGY
MILESTONE LOG
OMB Burden Disclosure Statement

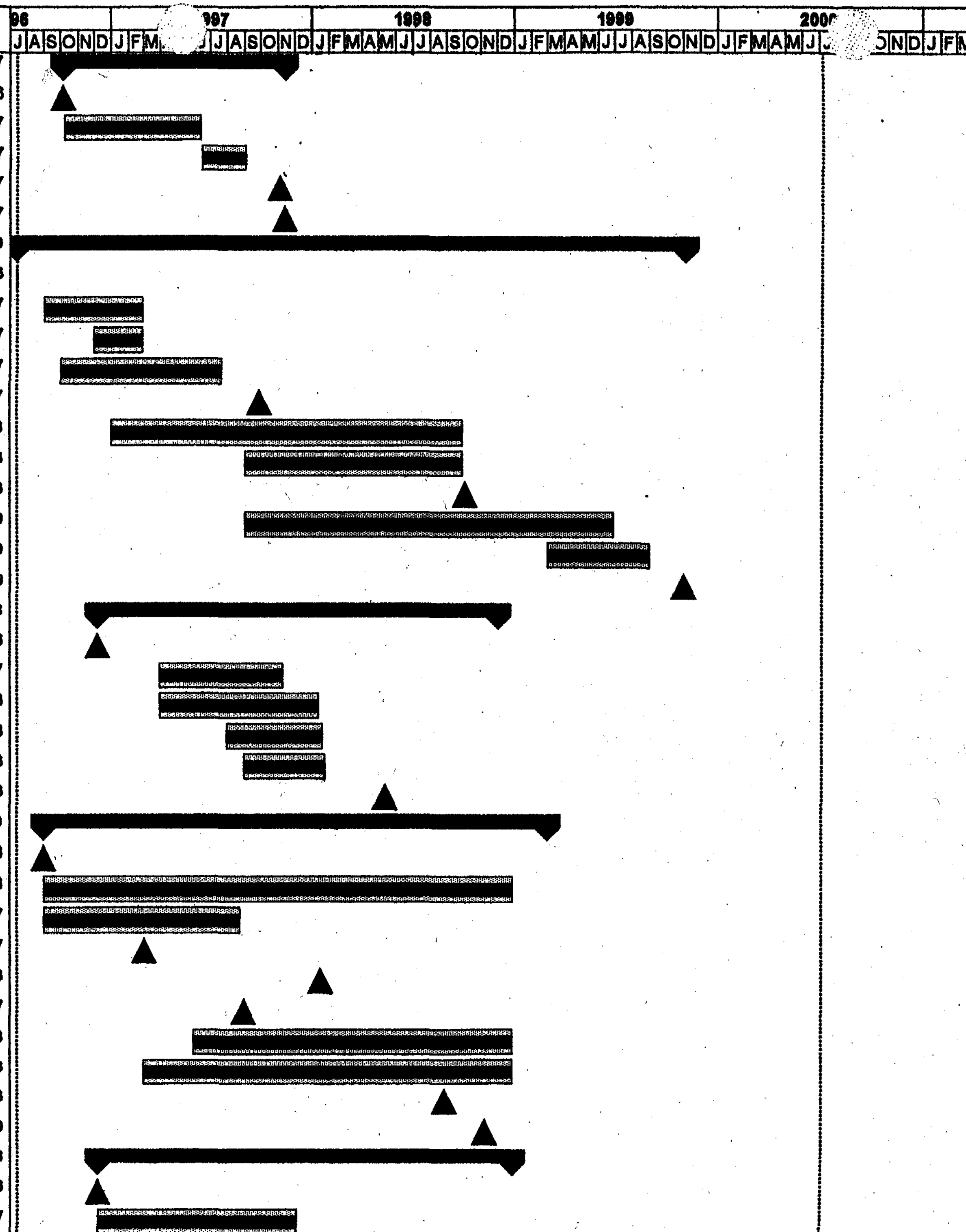
OMB Control No.
1910-0400

Cast Metal Coalition
PROGRAM/PROJECT TITLE

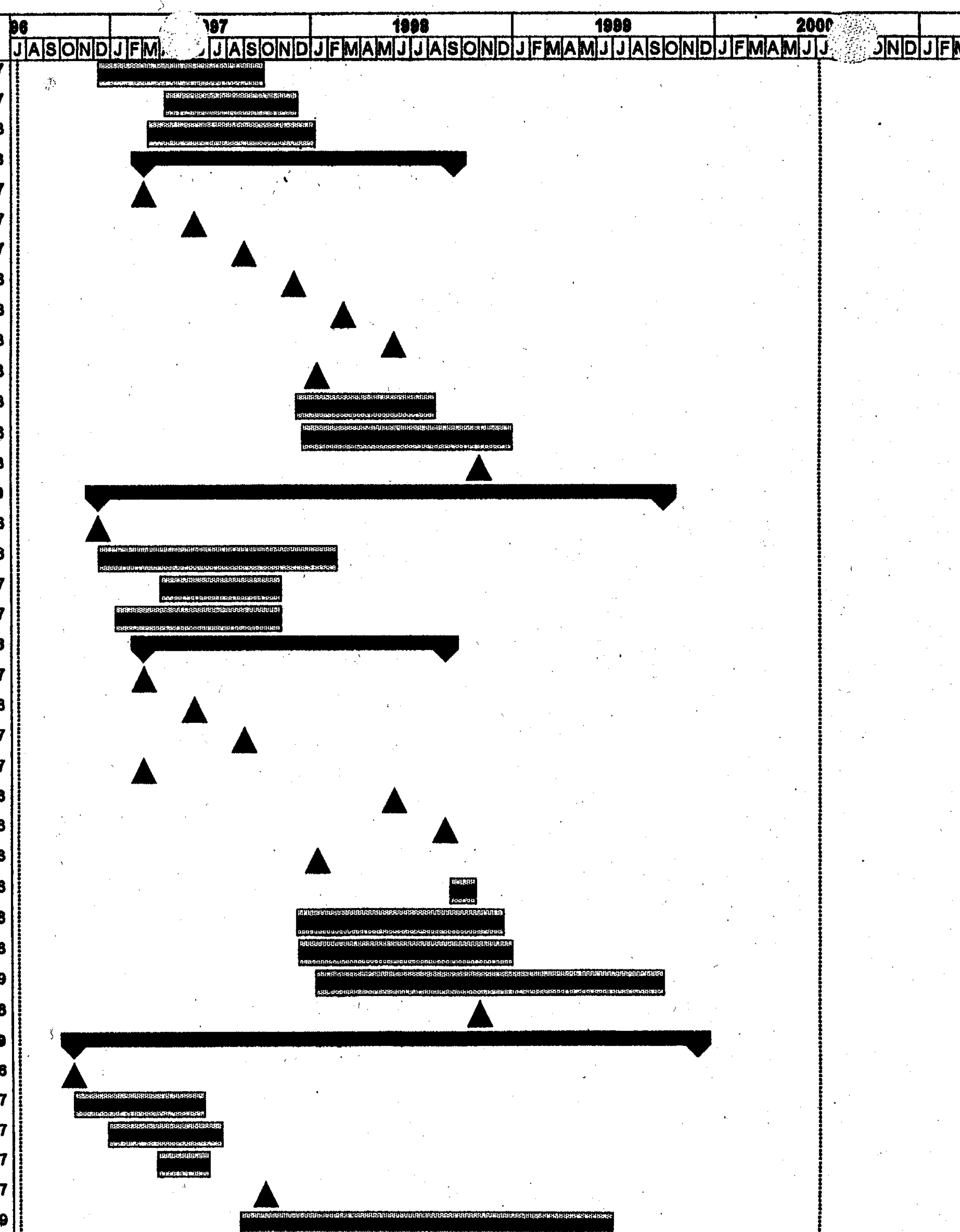
ID Number	Description	Planned Completion Date	Actual Completion Date	Comments
1.1	Energy Assessment, L.E.Griffith & Associates	11/14/97	11/14/97	COMPLETED
1.2	Yield Improvement, University of Iowa	9/2/98	11/4/99	COMPLETE
1.3	Late-Stream Inoculation Studies, Climax Research Services	2/28/98	1/15/99	COMPLETE
1.4	High Speed Milling & Pulsed ECM, Ohio State University	9/2/98	3/3/99	COMPLETE
1.5	Process Parameters, CANMET/MTL	12/8/98	12/98	COMPLETE
1.6	Design Parameters, CANMET/MTL	12/8/98	8/99	COMPLETE
1.7	Fast Shot Transition Point, Ohio State University	10/23/98	12/31/99	COMPLETE
1.8	Development of Database Design Rules, MPC	1/20/99	3/15/00	COMPLETE
1.9	Wear Analysis, University of Northern Iowa	5/31/98	12/14/98	COMPLETE
1.10	Residual Stress & Softening on Die Life, CWRU	12/8/98		COMPLETE
1.11	Microstructural Evaluation, University of Tennessee	5/30/97	6/30/97	COMPLETE

ID Number	Description	Planned Completion Date	Actual Completion Date	Comments
1.12	**Impurity Limits in Aluminum Bronzes, CANMET/MTL**	**10/24/98**	**7/30/99**	**COMPLETE**
1.13	**Steel Macro-Inclusions Atlas/ Elimination, Carnegie Mellon University**	**8/31/98**	**8/31/98**	**COMPLETE**
1.14	**Semi-Solid Metals Processing Consortium, WPI**	**7/14/98**	**12/18/98**	**COMPLETE**
1.15	**Properties of Squeeze & Semi-Solid Cast A356, CWRU**	**9/30/98**	**12/31/98**	**COMPLETE**
1.16	**Ferrite Determination, UT**	**6/30/98**	**3/31/99**	**DOE**
1.17	**Cast Particulate Metal Matrix Composites, UWM**	**11/14/98**	**1/6/99**	**DOE**
1.18	**Plasma Refining Process Development, Nupro**	**6/14/98**	**8/31/99**	**COMPLETE**
3.0	**Collaboration**	**7/14/99**	**7/30/00**	**COMPLETE**
3.1	Quarterly Reports	10/30/96	7/30/00	
3.2	Final Report	7/31/00	7/31/00	

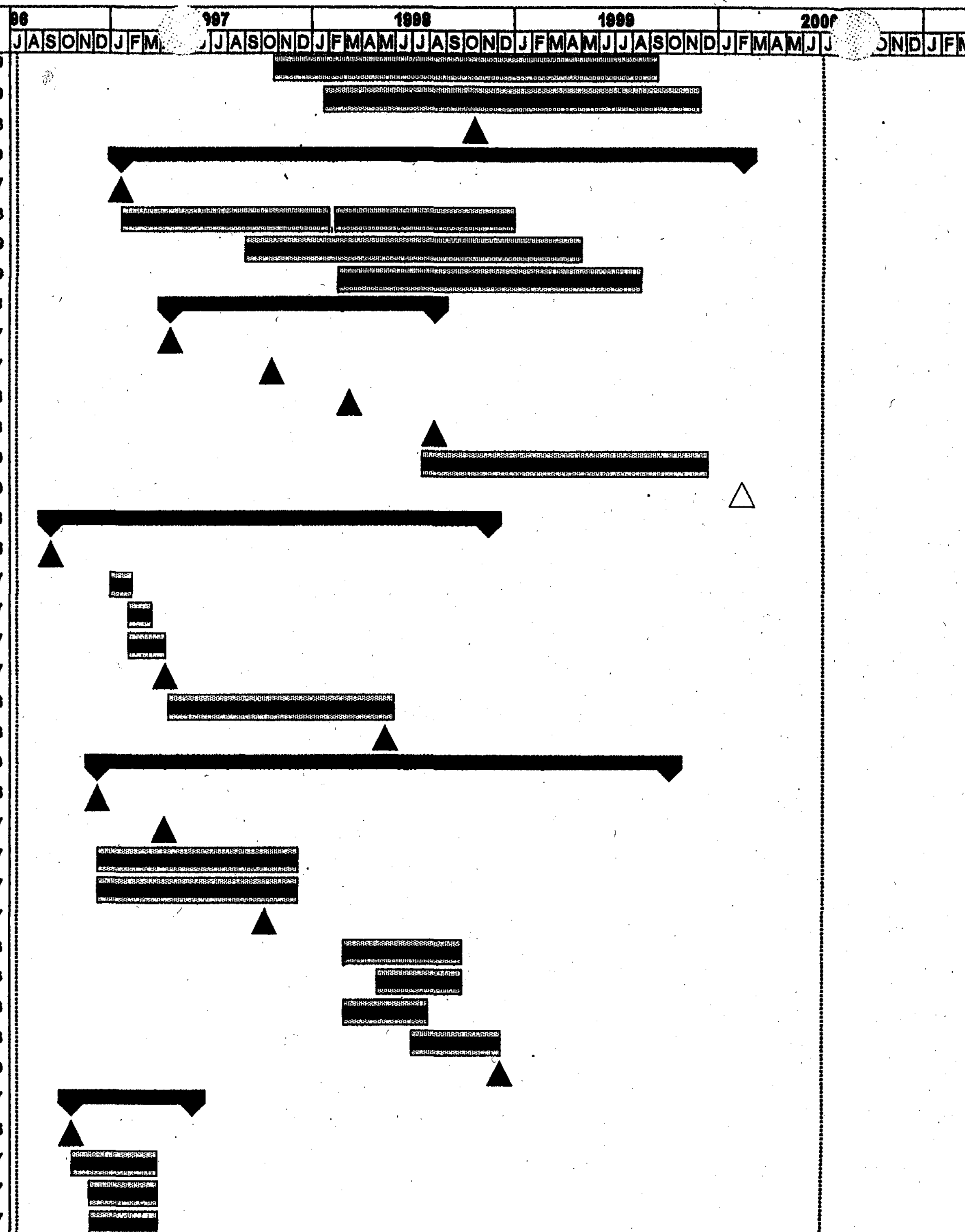
WBS	Task Na[illegible]	%	Finish
1.1	**Energy Assessment, L.E.Griffith & Associates**	100%	Fri 11/14/97
	Kickoff	100%	Mon 10/7/96
1.1.1	Assemble Energy Manual	100%	Fri 6/13/97
1.1.2	Develop Excel Spreadsheets	100%	Wed 9/3/97
1.1.3	Energy Booth	100%	Thu 11/6/97
1.1.4	Final Review	100%	Fri 11/14/97
1.2	**Yield Improvement, UI**	100%	Thu 11/4/99
	Kickoff	100%	Mon 7/15/96
1.2.1	Literature Review and Report	100%	Fri 2/28/97
1.2.2	Identify & Prioritize New YI Techniques - Report	100%	Fri 2/28/97
1.2.3	Conduct Survey and Provide Findings Report	100%	Tue 7/22/97
1.2.4	Year 1 Review	100%	Tue 9/30/97
1.2.5	Simple Part Shapes Techniques	100%	Wed 9/30/98
1.2.6	Casting Trials - Simple Part Shapes	100%	Wed 9/30/98
1.2.7	Year 2 Review	100%	Tue 10/6/98
1.2.8	Perform Simulations	100%	Wed 6/30/99
1.2.9	Prepare Manual	100%	Thu 9/2/99
1.2.10	Final Review	100%	Thu 11/4/99
1.3	**Late-Stream Inoculation Studies, CRS**	100%	Fri 12/4/98
	Kickoff	100%	Mon 12/9/96
1.3.1	Perform Melting Trials	100%	Tue 11/11/97
1.3.2	Perform Microstructure Evaluations	100%	Thu 1/15/98
1.3.3	Determine Properties of Exp. Castings	100%	Wed 1/21/98
1.3.4	Fatigue Testing	100%	Mon 1/26/98
1.3.5	Final Review	100%	Fri 12/4/98
1.4	**High Speed Milling and Pulsed ECM, OSU**	100%	Wed 3/3/99
	Kickoff	100%	Tue 9/3/96
1.4.1	Determine Influence of HSM on Surface Integrit	100%	Thu 12/31/98
1.4.2	Study PECM as Method for Improving Thermal I	100%	Tue 8/26/97
1.4.3	Review #1	100%	Tue 3/4/97
1.4.4	Report on Effect of Manufacturing Methods	100%	Sun 1/18/98
1.4.5	Year 1 Review	100%	Tue 9/2/97
1.4.6	Machining of Geometry Features by HSM	100%	Thu 12/31/98
1.4.7	Economic Evaluation	100%	Thu 12/31/98
1.4.8	Report on Strategies for Machining Various Ge	100%	Thu 12/31/98
1.4.9	Final Review	100%	Wed 3/3/99
1.5	**Process Parameters, CANMET/MTL**	100%	Thu 12/31/98
	Kickoff	100%	Mon 12/9/96
1.5.1	Mold Material Evaluation	100%	Mon 12/8/97



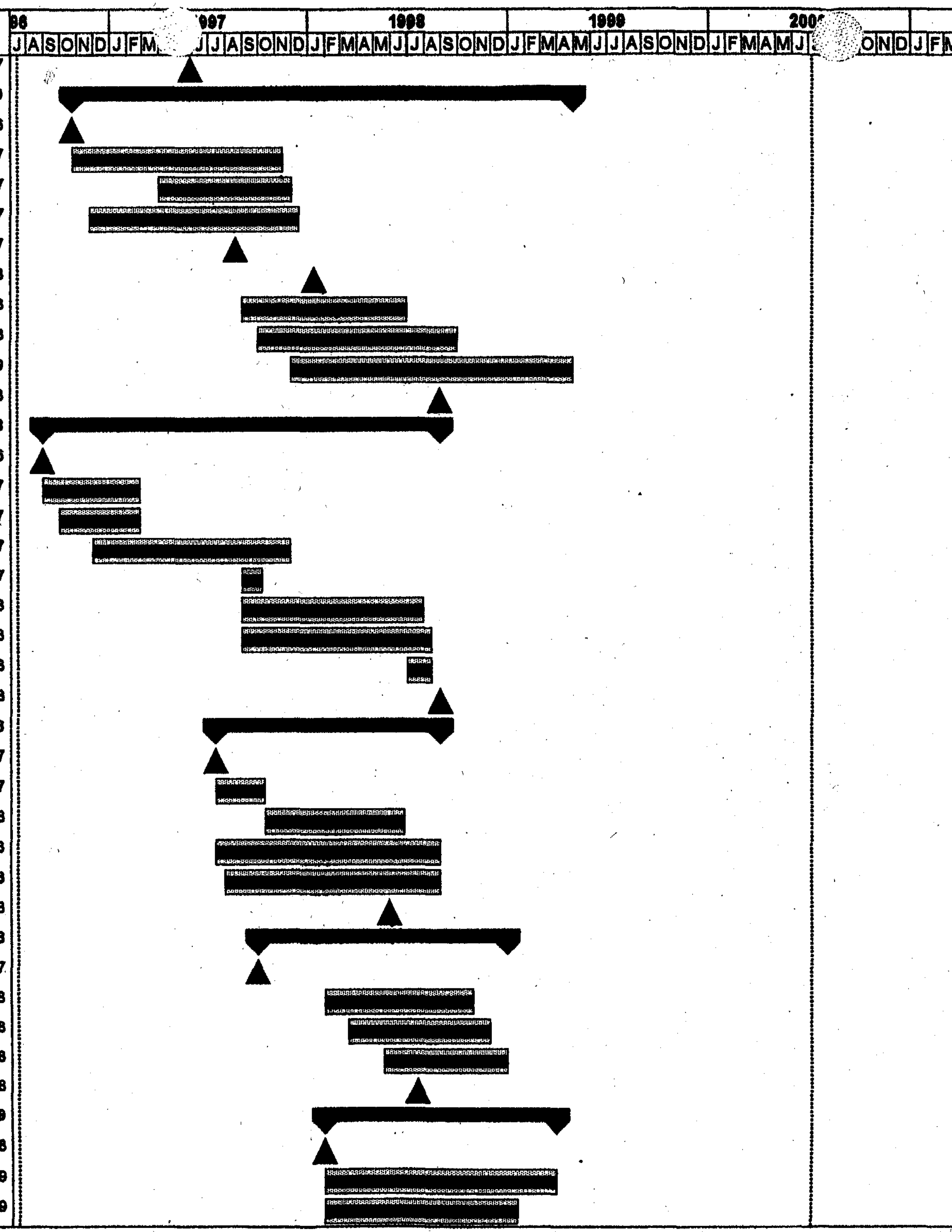
WBS	Task Na...	%	Finish
1.5.2	Examine Fluidity of Tin Bronzes/Red Brasses	100%	Wed 10/8/97
1.5.3	Grain Refinement Studies	100%	Mon 12/8/97
1.5.4	Water Modeling - Year 1	100%	Thu 1/8/98
1.5.5	**Progress Reports**	100%	Tue 9/15/98
1.5.5.1	Report #1	100%	Mon 3/3/97
1.5.5.2	Report #2	100%	Mon 6/30/97
1.5.5.3	Report #3	100%	Mon 9/1/97
1.5.5.4	Report #4	100%	Mon 3/30/98
1.5.5.5	Report #5	100%	Thu 7/16/98
1.5.5.6	Report #6	100%	Tue 9/15/98
1.5.6	Year 1 Review	100%	Tue 1/13/98
1.5.7	Water Modeling - Year 2	100%	Sat 8/15/98
1.5.8	Computer Modeling	100%	Thu 12/31/98
1.5.9	Year 2 Review	100%	Sun 11/1/98
1.6	**Design Parameters, CANMET/MTL**	100%	Thu 9/30/99
	Kickoff	100%	Mon 12/9/96
1.6.1	Examine Mechanical Properties - Year 1	100%	Tue 2/17/98
1.6.2	Wear Testing	100%	Fri 11/7/97
1.6.3	Metallography - Year 1	100%	Fri 11/7/97
1.6.4	**Progress Reports**	100%	Tue 9/1/98
1.6.4.1	Report #1	100%	Mon 3/3/97
1.6.4.2	Report #2	100%	Tue 6/30/98
1.6.4.3	Report #3	100%	Mon 9/1/97
1.6.4.4	Report #4	100%	Sun 3/30/97
1.6.4.5	Report #5	100%	Wed 7/15/98
1.6.4.6	Report #6	100%	Tue 9/1/98
1.6.5	Year 1 Review	100%	Tue 1/13/98
1.6.6	Slurry Work Testing	100%	Mon 10/26/98
1.6.7	Metallography - Year 2	100%	Tue 12/15/98
1.6.8	Mechanical Properties - Year 2	100%	Thu 12/31/98
1.6.9	Corrosion Studies	100%	Thu 9/30/99
1.6.10	Year 2 Review	100%	Sun 11/1/98
1.7	**Fast Shot Transition Point, OSU**	100%	Tue 11/30/99
	Kickoff	100%	Wed 10/23/96
1.7.1	Select Part Geometries	100%	Wed 6/18/97
1.7.2	Modify Prince Test Stand	100%	Mon 7/21/97
1.7.3	Procure High Speed Video Equipment	100%	Fri 6/27/97
1.7.4	Year 1 Review	100%	Wed 10/8/97
1.7.5	Perform Computer Simulations of Filling	100%	Wed 6/30/99



WBS	Task Na	%	Finish
1.7.6	Manufacture Transparent Die Sets	100%	Wed 9/15/99
1.7.7	Water Analog Tests	100%	Tue 11/30/99
1.7.8	Year 2 Review	100%	Thu 10/22/98
1.8	**Development of Database Design Rules, MPC**	100%	Tue 2/15/00
	Kickoff	100%	Mon 1/20/97
1.8.1	Mechanical Testing	100%	Thu 12/31/98
1.8.2	Development of ATLAS	100%	Fri 4/30/99
1.8.3	Propose/Validate Screening Test	100%	Tue 8/17/99
1.8.4	**Reviews**	100%	Wed 8/12/98
1.8.4.1	Review #1	100%	Mon 4/21/97
1.8.4.2	Review #2	100%	Mon 10/20/97
1.8.4.3	Review #3	100%	Tue 3/10/98
1.8.4.4	Review #4	100%	Wed 8/12/98
1.8.5	Recommendations ASTM/API	100%	Wed 12/15/99
1.8.6	Final Review	100%	Tue 2/15/00
1.9	**Wear Analysis, UNI**	100%	Sun 11/15/98
	Kickoff	100%	Mon 9/16/96
1.9.1	Test Specimen Construction	100%	Mon 2/10/97
1.9.2	Pattern Shipment	100%	Tue 3/18/97
1.9.3	Pattern Mounting & Testing (First Round)	100%	Fri 4/11/97
1.9.4	Patterns Sent to CMI International	100%	Fri 4/11/97
1.9.5	Pattern Mounting & Testing (Rounds 2-5)	100%	Sat 5/30/98
1.9.6	Final Review	100%	Sun 11/15/98
1.10	**Residual Stress & Softening on Die Life, CWRU**	100%	Wed 10/6/99
	Kickoff	100%	Mon 12/9/96
1.10.1	Review #1	100%	Mon 6/9/97
1.10.2	Residual Stress Measurements	100%	Mon 12/8/97
1.10.3	Softening Measurements	100%	Mon 12/8/97
1.10.4	Year 1 Review	100%	Wed 10/8/97
1.10.5	Measurement & Validation on Calibrated Speci	100%	Wed 9/30/98
1.10.6	Controlled Thermal Cycling Exp on Pentium Gr	100%	Wed 9/30/98
1.10.7	Measurements on Used Die Inserts	100%	Fri 7/31/98
1.10.8	Data Processing and Analysis	100%	Tue 12/8/98
1.10.9	Year 2 Review	100%	Wed 10/6/99
1.11	**Microstructural Evaluation, UT**	100%	Fri 5/30/97
	Kickoff	100%	Wed 10/23/96
1.11.1	Optical Light Microscopy	100%	Thu 3/27/97
1.11.2	Scanning Electron Microscopy	100%	Fri 3/28/97
1.11.3	Identify Precipitates	100%	Fri 3/28/97



WBS	Task Na...	%	Finish
1.11.4	Final Review	100%	Fri 5/30/97
1.12	**Impurity Limits in Aluminum Bronzes, CANMET/N**	100%	Fri 4/30/99
	Kickoff	100%	Fri 10/25/96
1.12.1	Alloy Preparation	100%	Sat 11/15/97
1.12.2	Heat Treatment	100%	Mon 12/1/97
1.12.3	Microstructural Examination	100%	Mon 12/15/97
1.12.4	Presentation at AFS Casting Congress	100%	Mon 12/1/97
1.12.5	Year 1 Review	100%	Tue 1/13/98
1.12.6	Alloy Preparation for 2nd Year	100%	Tue 6/30/98
1.12.7	Mechanical Properties	100%	Wed 9/30/98
1.12.8	Weldability Studies	100%	Fri 4/30/99
1.12.9	Year 2 Review	100%	Mon 8/31/98
1.13	**Steel Macro-Inclusions Atlas/Elimination, CMU**	100%	Mon 8/31/98
	Kickoff	100%	Sun 9/1/96
1.13.1	Review Previous Data & Literature	100%	Wed 2/26/97
1.13.2	Conduct Initial Survey of Samples from Industry	100%	Wed 2/26/97
1.13.3	Complete Equilibrium Phase Diagrams	100%	Sat 11/29/97
1.13.4	Year 1 Review	100%	Wed 10/8/97
1.13.5	Determine Mechanisms of Formation	100%	Thu 7/30/98
1.13.6	Relationship between Process and Inclusion Fc	100%	Sat 8/15/98
1.13.7	Documentation & Completion of Web Site	100%	Sat 8/15/98
1.13.8	Year 2 Review	100%	Mon 8/31/98
1.14	**Semi-Solid Metals Processing Consortium, WPI**	100%	Mon 8/31/98
14.1	Kickoff	100%	Tue 7/15/97
1.14.1	Finalize Single Phase Model	100%	Mon 10/13/97
1.14.2	Two Phase Model & Preliminary Calculations	100%	Thu 6/25/98
1.14.3	Viscosity Measurements	100%	Mon 8/31/98
1.14.4	Experimental Program (Oak Ridge)	100%	Mon 8/31/98
1.14.5	Year 1 Review	100%	Fri 5/29/98
1.15	**Properties of Squeeze & Semi-Solid Cast A356, C**	100%	Thu 12/31/98
15.1	Kickoff	100%	Wed 10/1/97
1.15.1	Heat Treat/Machine Specimens	100%	Fri 10/30/98
1.15.2	Perform Room Temperature Tensile Tests	100%	Mon 11/30/98
1.15.3	Apply Models Correlating Structure to Tensile F	100%	Thu 12/31/98
1.15.4	Year 1 Review	100%	Thu 10/22/98
1.16	**Ferrite Determination, UT**	100%	Wed 3/31/99
16.1	Kickoff	100%	Sun 2/1/98
1.16.1	Literature Review	100%	Wed 3/31/99
1.16.2	Machining & Preparation of Samples	100%	Wed 1/20/99



WBS	Task Name	%	Finish
1.16.3	Year 1 Review	100%	Thu 11/5/98
1.17	**Cast Particulate Metal Matrix Composites, UWM**	100%	Wed 1/6/99
17.1	Kickoff	100%	Sun 12/6/98
1.17.1	Evaluation of Mechanical Properties	100%	Fri 11/6/98
1.17.2	Distribution of Test Bars	100%	Wed 1/6/99
1.17.3	Casting & Qualification of Test Bars	100%	Sat 11/14/98
1.17.4	Year 1 Review	100%	Wed 12/2/98
1.18	***Plasma Refining Process Development, Nupro Cc***	100%	Tue 8/31/99
18.1	Kickoff	100%	Wed 10/15/97
1.18.1	Literature Review	100%	Fri 12/12/97
1.18.2	Melt CN7M Stainless Steel	100%	Fri 2/27/98
1.18.3	Welding Tests	100%	Wed 5/26/99
1.18.4	Corrosion Tests	100%	Wed 5/26/99
1.18.5	Decarburize in Plasma Ladle Furnace	100%	Sat 3/14/98
1.18.6	Final Review	100%	Tue 8/31/99
3.0	**Collaboration**	100%	Mon 7/31/00
	Kickoff	100%	Mon 7/15/96
3.1	**Quarterly Reports**	100%	Fri 4/28/00
3.1.1	Review #1	100%	Thu 10/31/96
3.1.2	Review #2	100%	Thu 1/30/97
3.1.3	Review #3	100%	Wed 4/30/97
3.1.4	Review #4	100%	Wed 7/30/97
3.1.5	Review #5	100%	Thu 10/30/97
3.1.6	Review #6	100%	Fri 1/30/98
3.1.7	Review #7	100%	Thu 4/30/98
3.1.8	Review #8	100%	Thu 7/30/98
3.1.9	Review #9	100%	Fri 10/30/98
3.1.10	Review #10	100%	Fri 1/29/99
3.1.11	Review #11	100%	Fri 4/30/99
3.1.12	Review #12	100%	Fri 7/30/99
3.1.13	Review #13	100%	Mon 11/1/99
3.1.14	Review #14	100%	Mon 1/31/00
3.1.15	Review # 15	100%	Fri 4/28/00
3.2	End-of-Program Final Review	100%	Mon 7/31/00