BOILER MATERIALS FOR ULTRASUPERCRITICAL COAL POWER PLANTS

U.S. DOE NO.: DE-FG26-01NT41175
OCDO NO.: D-00-20

First Quarterly Report for FY 2006 October 1 – December 30, 2005

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January 31, 2006

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Abstract

The U.S. Department of Energy (DOE) and the Ohio Coal Development Office (OCDO) have recently initiated a project aimed at identifying, evaluating, and qualifying the materials needed for the construction of the critical components of coal-fired boilers capable of operating at much higher efficiencies than current generation of supercritical plants. This increased efficiency is expected to be achieved principally through the use of ultrasupercritical steam conditions (USC). A limiting factor in this can be the materials of construction. The project goal is to assess/develop materials technology that will enable achieving turbine throttle steam conditions of 760°C (1400°F)/35 MPa (5000 psi). This goal seems achievable based on a preliminary assessment of material capabilities. The project is further intended to build further upon the alloy development and evaluation programs that have been carried out in Europe and Japan. Those programs have identified ferritic steels capable of meeting the strength requirements of USC plants up to approximately 620°C (1150°F) and nickel-based alloys suitable up to 700°C (1300°F). In this project, the maximum temperature capabilities of these and other available high-temperature alloys are being assessed to provide a basis for materials selection and application under a range of conditions prevailing in the boiler. This report provides a quarterly status report for the period of October 1 to December 30, 2005.

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Executive Summary

A. Project Objective

The principal objective of this project is to develop materials technology for use in ultrasupercritical (USC) plant boilers capable of operating with 760°C (1400°F), 35 MPa (5000 psi) steam.

B. Background and Relevance

In the 21st century, the world faces the critical challenge of providing abundant, cheap electricity to meet the needs of a growing global population while at the same time preserving environmental values. Most studies of this issue conclude that a robust portfolio of generation technologies and fuels should be developed to assure that the United States will have adequate electricity supplies in a variety of possible future scenarios.

The use of coal for electricity generation poses a unique set of challenges. On the one hand, coal is plentiful and available at low cost in much of the world, notably in the U.S., China, and India. Countries with large coal reserves will want to develop them to foster economic growth and energy security. On the other hand, traditional methods of coal combustion emit pollutants and CO₂ at high levels relative to other generation options. Maintaining coal as a generation option in the 21st century will require methods for addressing these environmental issues.

This project has established a government/industry consortium to undertake a five-year effort to evaluate and develop advanced materials that allow the use of advanced steam cycles in coal-based power plants. These advanced cycles, with steam temperatures up to 760°C, will increase the efficiency of coal-fired boilers from an average of 35% efficiency (current domestic fleet) to 47% (HHV). This efficiency increase will enable coal-fired power plants to generate electricity at competitive rates (irrespective of fuel costs) while reducing CO₂ and other fuel-related emissions by as much as 29%.

Success in achieving these objectives will support a number of broader goals. First, from a national prospective, the program will identify advanced materials that will make it possible to maintain a cost-competitive, environmentally acceptable coal-based electric generation option. High sulfur coals will specifically benefit in this respect by having these advanced materials evaluated in high-sulfur coal firing conditions and from the significant reductions in waste generation inherent in the increased operational efficiency. Second, from a national prospective, the results of this program will enable domestic boiler manufacturers to successfully compete in world markets for building high-efficiency coal-fired power plants.

The project is based on an R&D plan developed by the Electric Power Research Institute (EPRI) that supplements the recommendations of several DOE workshops on the subject of advanced materials. In view of the variety of skills and expertise required for the successful completion of the proposed work, a consortium that includes EPRI and the major domestic boiler manufacturers (Alstom Power, Babcock and Wilcox (a division of McDermott Technologies Inc.), Foster Wheeler, Riley Power Inc., and Oak Ridge National Labs) has been developed.

C. Project Tasks

The project objective is expected to be achieved through 9 tasks as listed below:

Task 1.	Conceptual Design and Economic Analysis
Task 2.	Mechanical Properties of Advanced Alloys
Task 3.	Steamside Oxidation Resistance
Task 4.	Fireside Corrosion Resistance
Task 5.	Welding Development
Task 6.	Fabricability
Task 7.	Coatings
Task 8.	Design Data and Rules
Task 9.	Project Integration and Management

D. Major Accomplishments during the Quarter

- Creep tests for CCA617 have exceeded 23,000 hours and results have exceeded expectations in the lower temperature regime. This benefit may extend to 730°C.
- Aged and un-aged Inconel 740 show little difference in fatigue testing.
- Welds in HR6W will not require a weld strength reduction factor as rupture tests fail in the base metal.
- Pressurized U-bend rupture tests were completed in HR6W and two alloy 230 bends.
- Steamside oxidation testing is complete for 650°C and 800°C. Differences between B&W and ORNL test procedures were determined. Effects of shot blasting were also presented as well as exfoliation data.
- Evaluation of laboratory fireside testing continued. Results are included in the attachments. The test loop at Niles operated at rated temperature. Finalization of the first two air-cooled corrosion probes continued.
- Welding development is essentially complete except for SAVE12 and IN 740. Much progress was made on the IN 740 welding and the material supplier has

been working on developing a heat that would be less susceptible to liquation cracking.

- Re-crystallization studies continued.
- Swaging trials were successful on alloy 230.
- A demonstration article of nested alloy 230 tubing with other short pieces of alloy tubing was completed. Work on another demonstration article demonstrating welding tubing into a header began.
- Coating efforts concentrated on diffusion coating of tubing internal surfaces.

E. Plans for the Next Quarter

It is anticipated that the following work will be completed during the next quarter:

- Continue U-bend testing on IN 740.
- Install air-cooled fireside corrosion test probes and begin tests at first two sites.
- Continue welding efforts on IN 740 and SAVE12.

F. Issues

- Funding concerns at ORNL is limiting testing of new samples.
- The host site for the third air-cooled fireside corrosion probe has not been finalized. This alternate site is because of the original site changing coal types.
- Inconel 740 seems to have heat to heat sensitivity to microfissuring.

2.0 Taskwise Status

Task 1 Conceptual Design and Economic Analysis (Task lead EPRI)

The objective of Task 1 is to specify the temperature/pressure distribution for 760°C/35 MPa (1400°F/5000 psi) steam inlet conditions so that the data needs and the range of test parameters can be identified and the economics of material selection established.

Task 1A: Alstom Approach (Alstom Power Co.)

Objectives:

The primary objectives of this subtask are:

- Develop a conceptual boiler design for a high efficiency ultra supercritical cycle designed for 1400°F steam temperature.
- Identify tubing and piping materials needed for high temperature surface construction.
- Estimate gas and steam temperature profiles so that appropriate mechanical, corrosion and manufacturing tests of materials could be designed and conducted to prove suitability of the selected alloys.

Progress for the Task

A final report has been completed and distributed.

Task 1B: Babcock Approach

Objective:

The objectives of this subtask are the same as in Subtask 1A.

Progress for the Quarter:

No work was performed on this task this quarter.

Concerns:

Progress for the Next Quarter:

A final report has been completed and distributed.

Task 1C: Economic Analysis

Objective:

The objective of this task is to determine relative economics of the USC plant.

Progress for the Task:

A final report has been completed and distributed.

Concerns:

None

Task 2

Mechanical Properties of Advanced Alloys (ORNL)

The objective of Task 2 is to produce the mechanical properties database needed to design a boiler to operate at the steam conditions within the scope of the project.

Task 2A: Assessment of the Alloy Performance Requirements

Objectives:

The primary objectives of this subtask are:

- Focus on performance needed for boiler service in the temperature range of 650°C (1200°F) to 871°C (1600°F).
- Produce reports that justify the materials selected for the pressure retention components of the USC boiler.

Progress for the Task:

ORNL attended the European Creep Collaborative Committee's (ECCC) 2005 Conference on Creep and Fracture in High-Temperature Components in London, UK (Sept. 2005). A number of issues dealing with USC boiler material technology were presented and ORNL will brief the consortium on the main issues during the next steering committee meeting.

Task 2B: Detailed Test Plan

Objectives:

The detailed mechanical properties test plan is intended to provide guidance on the scope of the mechanical testing for each material to support the resolution of issues related to the tasks undertaken in the project. Categories include: mechanical characterization; data production for the development of code cases; effects of fabrication variables; weldment performance; fatigue and thermal-fatigue behavior; and the like. The six alloys, chemical compositions in Table 1 below, of most interest to the project are: SAVE12, Super 304H, HR6W, Haynes 230, CCA617, and INCONEL 740. Specific heat chemistries are available on the website.

Progress:

The characterization testing plans have been completed for the creep-rupture testing of the five tubing alloys (Super 304H, HR6W, alloy 230, CCA617, and INCONEL 740). A test plan for the creep-rupture testing of Inconel 740 plate and SAVE12 pipe have also been produced. Progress and/or problems associated with the welding (Task 5) and

fabrication (Task 6) tasks will define relevant testing. Thus, to some measure the test plan continues to evolve. The weldment test plan for HR6W is now complete. Test plans for Super 304H, CCA617, and Super 304H to CCA617 tubes have been produced. A test plan to evaluate 740 and 263 weld filler metals on Inconel 740 has been designed and testing has been completed. Thick section weldments plans are being produced as welded material becomes available. Test matrices for verifying and determining the LCF and creep-fatigue behavior of CCA617 and Inconel 740 have been designed and testing initiated. Discussions with Task 8 members have helped define the structural tests needed by the boiler manufacturers to evaluate their respective component models. Notched bar test plans for Inconel 740 have been produced to evaluate the material's notch sensitivity and multi-axial creep behavior.

TABLE 1. Compositions of USC Steam Boiler Consortium Materials															
Alloy	Nominal Compositions in Wt%											Si	N	Cu	Other
	Fe	Cr	Ni	Mn	Mo	Ti	Nb	W	V	C	B				
SAVE 12*	bal	11.0		0.2				3.00	0.20	0.10		0.3	0.04		3.0Co 0.07Ta 0.04Nd
Super 304H*	bal	18.0	9.0	0.8			0.40			0.10		0.2	0.10	3.00	
HR6W*	bal	23.0	43.0	1.2		0.08	0.18	6.00		0.080	0.003	0.4			
Haynes 230*	3.0	22.0	bal	0.5	2.0			14.00		0.10	0.02	0.4			5.0Co 0.3Al 0.02La
CCA617	0.6	21.7	bal	0.03	8.6	0.40				0.05	0.002	0.1	0.01	0.01	11.25Co 1.25Al
INCONEL 740	2	24.0	bal	0.3	0.5	2.0	2.0			0.07	0.002	0.5			19.8Co 0.8Al 0.015Zr

*Compositions are nominal and will be replaced by measured compositions in the future

Concerns:

None.

Task 2C: Long Term Creep Strength

Objectives:

The primary objectives of this subtask are:

- Identify the general characteristics of the creep behavior and damage accumulation in the candidate alloys.
- Verify the creep-strength of code-approved alloys.
- Assess the creep-strength non code-approved alloys; and provide creep/creep-rupture data for a code case if deemed appropriate by consortium members.
- Provide accurate creep data (i.e. creep-curves) for boiler design on the candidate materials.

Progress:

The creep-rupture test matrix for the HR6W tubing is now complete. The results confirm earlier predictions based off short-term data which indicated that the HR6W did not have a creep strength advantage compared to current austenitic boiler tubing. Sumitomo has contacted ORNL to provide material from a new 'high creep strength' heat of HR6W. ORNL has asked for the mechanical properties data to evaluate the strength of the alloy before agreeing to more testing. As of December 30, 2005, Sumitomo has not responded to ORNL's request. The CCA617 alloy is exceeding expectations in the lower temperature regime (650°C to 700°C), based on performance equivalent to alloy 617. Three creep tests have now exceeded 23,000 hours for CCA617. Microstructural studies suggest this strength difference is due to the precipitation of gamma prime at 700 to 800°C. Grain size control and boron content may also be factors in the strength of CCA617. Larson-Miller-Parameter extrapolation shows the creep strength benefit may extend to 730°C for CCA617 vs. std. 617. All of the planned Super 304H tests continue. Testing is also progressing on the INCONEL 740 tubing and plate. 100 and 1000 hours rupture lives appear close to predictions based off previous work at ORNL and data from Special Metals but longer term tests are slightly shorter than predicted. The longest test times have reached approximately 8,000 hours and lower stress tests have been added to the matrix with expected rupture lives of 10,000 to 20,000 hours.

Task 2D: Microstructural Analysis

Objective:

The primary objectives of this subtask are:

- Identify the microstructural changes that lead to significant changes in the strengthening, weakening, and internal damage characteristics of each material.
- Explore how these changes relate to the exposure conditions of the testing.

Progress:

The University of Cincinnati, subcontract with ORNL to provide electron microscopy studies on aged and creep tested material, is completing its yearly report. This will be submitted to ORNL for review next quarter.

Task 2E: Assessment of Creep-Fatigue Properties

Objective:

The primary objectives of this subtask are:

- Verify the low cycle fatigue, creep-fatigue, and thermal mechanical fatigue properties of the thick section alloys.
- Develop a database that will lead to practical, yet conservative methods for new materials.
- Address the issue of creep-fatigue in the boiler materials.

Progress:

LCF testing on Inconel 740 (Heat #BLT2819 - plate) was started this quarter. A summary of the results, to date, is in the appendix. More tests will be required to establish the baseline behavior of the 740 base metal and creep-fatigue tests are planned as well. The results have not been updated on the website. ORNL is determining the best way to put the large LCF datafiles on the website. A comparison plot of the LCF behavior of the CCA617 and Inconel 740 is shown in the appendix. One test continues beyond 200,000 cycles. A comparison test between aged and unaged 740 showed little difference in cycle life at 750°C.

An additional LCF testing machine has been under refurbishment this quarter. A new resistance furnace was designed and built for the system. This should help with longer-term LCF and C-F testing when thermal stability is particularly important. Long-term tests using an induction heating furnace have been shut down due to problems with the heating unit. These shutdowns were due to poor cooling water flow and/or changes in the temperature gradients in the specimen after prolonged testing.

Task 2F: Modeling of Weld Joints

Objectives:

The primary objectives of this subtask are:

- Produce the experimental data needed to model dissimilar metal and thick-section weld joints.

Progress:

Rupture testing was completed on HR6W butt-welded tubes. The results confirmed that the HR6W was weaker than the 82 and 617 weldments. Thus by overmatching the weld metal, HR6W does not require a weld stress reduction factor. Creep-rupture testing continues on Haynes ® 230 plate weldments. A weld strength factor of 0.8 (80% of base metal strength) has been observed for the various GTAW weldments made in the tube and thin plate. A plot of WSF results for Haynes 230 is included in the appendix. Short-term cross-weld creep-rupture testing has been completed on a 5/8" thick Inconel 740 plate welded with both 740 and 263 filler metal. The purpose of these tests was to evaluate the differences between the weld strength of the two filler metals.

Wrought Inconel 740 has superior creep strength compared to wrought 263 but data is not available on the weld metal strength for these alloys. 263 is the preferred filler from a weldability standpoint for joining 740. Based on the results shown in the plot in the appendix (max rupture time of 2,000 hours), the 263 weld metal creep-rupture strength is greater than that of the 740. All ruptures were in the weld metal irrespective of weld metal type. Microstructure studies are ongoing to understand the differences in creep strength. Testing is ongoing for the large cross-weld specimens from the SAW and SMAW CCA617 2" thick plate weldments. The specimen dimensions being tested are: 16" overall specimen length with a gauge section 5.5" long x .32" thick x .75" wide. Testing of butt-welded tubes of CCA617, Super304H, and CCA617 to Super304H started this quarter. Initial results on the Super 304H to CCA617 DMW produced ruptures in the Super 304H base metal as expected. The 3" thick Haynes 230 weldment has been received, but machining of specimens has not begun due to FY06 funding considerations.

Task 2G: Study of Accelerated Test Methods

Objectives:

The primary objective of this task is:

- Provide a method to rapidly characterize changes in the strength of candidate materials.

Progress:

No new materials have been identified for relaxation testing. This task is complete until an evaluation of a new material is needed or Task 8 determines a critical data need.

Task 2H: Model Validation

Objectives:

The primary objective of this task is:

- Produce a database that can be used to confirm or validate design rules that are developed in Task 8.

Progress:

Pressurized creep testing of tube U-bends, to evaluate coldwork effects, were completed on the HR6W tube bend and two Haynes 230 bends. The Haynes 230 bends were stopped after testing for 8,000 hours without rupturing, but the HR6W was removed upon rupture after 7108.9 hours. All specimens were measured and have been sectioned for metallography. The tabular O.D. creep strain measurements are

given in the appendix. For the Haynes 230 bends tested, the bend with the higher cold strain showed more creep deformation compared to the bend with lower strain.

Pressurized creep testing of three Inconel 740 tube bends has started. Haynes 230 end caps were welded to the 740 tube bends using Nimonic 263 filler. The welds passed radiographic inspection this quarter. Testing is being performed at 800°C and 7040psi. The estimated rupture time for these tests is 20,000 hours. Thus, assuming cold work decreases the rupture life of the material; ruptures are expected within the 8,000 hours planned test time.

Thermal shock testing on a CCA617 tube continued this quarter. Over 2000 thermal cycles have been complete with a 300 to 400°C upshock temperature gradient through the wall of the tube. Significant fatigue cracking was observed after 3000 cycles. A picture is included in the appendix. A RTV replica was taken to evaluate the observed cracking. After an additional 1,000 cycles, the specimen will be removed and studied again. Additionally, a Super 304H thermal shock specimen was fabricated this quarter.

Concerns:

Decrease in funding for FY06 will impact some testing activities. A list of potential impacts will be presented at the consortium steering committee meeting for review and comment. Current testing activities will not be impacted but new testing will be delayed until FY2007.

Plans for Next Quarter:

Creep-rupture testing of all materials will continue. Pressurized creep testing of Inconel 740 tube bends will continue and creep strain measurements will be made. LCF testing will be started for Haynes 230 from the 3" thick plate. Testing of weldments, including the thick section welds of the CCA617, will continue. Thermal shock testing of CCA617 will continue and testing of Super 304H will start. The website will be updated.

Task 3 Steamside Oxidation (B&W)

Task 3A: Autoclave Testing

Background:

Steamside oxidation tests will be performed on commercially available and developmental materials at temperatures between 650°C and 900°C (1202°F - 1652°F).

Experimental:

During the past quarter, evaluation of the specimens removed following the third exposure at 800°C was completed. Also during the past quarter, materials for the 900°C exposure were selected.

Descaled Weight Lost

The descaled weight loss results after 4,000 hours of exposure in 800°C steam indicated that the high aluminum content nickel based material Alloy 214 exhibited the best oxidation behavior. The nickel-based materials CCA617, Alloy 740 and Alloy 230 displayed the best oxidation behavior of the candidate USC alloys. The ferritic material VM12 continued to display oxidation rates comparable to austenitic materials that contained greater than 19% chromium. Austenitic stainless steels that contained less than 19% chromium continued to display poor oxidation behavior.

A comparison of the B&W steamside oxidation results with the ORNL steamside oxidation results was made. In many cases there is good general agreement between the B&W and the ORNL data. It must be remembered that the ORNL tests were performed under somewhat different environmental conditions than the B&W tests:

- B&W uses OT water (pH 8-8.5; 100-300 ppb O₂), ORNL uses deaerated deionized water.
- B&W tests at atmospheric pressure, ORNL tests at 250 psig.

Effect of Shot Blasting

The effect of ID shot blasting on the steamside oxidation of SUPER304H and 347HFG was evaluated. The results suggest that shot blasting is effective in improving the oxidation behavior of these materials.

Oxide Appearance/Morphology and Chemistry

The results from the SEM/EDS evaluation of the materials exposed for up to 4,000 hours in 800°C steam indicate that the ferritic materials possess a mixed chromium/iron

oxide, with the exception of VM12 which exhibited a dense chromium oxide. The austenitic materials all formed an outer chromium oxide, with the exception of Alloy 214 which formed an aluminum oxide. Some austenitic materials also formed an inner silicon oxide. Austenitic materials containing significant aluminum content continued to display intergranular aluminum oxide penetrations below the oxide.

Exfoliation

Some degree of exfoliation was observed in most of the test materials. After 4,000 hours of exposure in 800°C steam, the materials that did not appear to experience exfoliation were VM12, Alloy 214, CCA617 and Alloy 740. The austenitic stainless steels containing less than 19% chromium experienced the greatest amount of exfoliation. Results suggest that shot blasting improves the exfoliation behavior of S304H and 347HFG.

900°C Test Materials

Based on input provided from consortium members, the materials selected for inclusion in the 900°C steam oxidation test are shown in Table 1.

TABLE 1

Materials to be Tested in Steam at 900°C				
Ferritics	300-Series Austenitics	Other Austenitics	Chromized	Welds
VM12	304H	Nimonic 263	ChromizedS304H	Alloy 230 Weld
MARB2	347HFGTube	CCA617	SiChromizedS304H	CCA617 Weld
P92	Shot Blasted 347HFGTube	Alloy 230	AlChromizedS304H	Alloy 740 Weld
SAVE12	SUPER304H	Alloy 740		
	SUPER304H Tube	HR120		
	Shot Blasted SUPER304HTube	2025Nb		
	310HCbN	SAVE25		
	Deep Rolled 347HFG	HR6W		
		RA602CA		
		Alloy 214		
		Alloy 282		

Concerns:

None.

Activities Next Quarter:

Contingent upon sufficient funding, specimens will be prepared for the 900°C exposure, and the first exposure at 900°C will begin.

Task 3B Coating Tests

Background:

Coated specimens for steamside oxidation testing will be prepared in conjunction with Task 7 and evaluated after testing.

Experimental:

The descaled weight loss results from the 800°C exposure consistently indicate that the SiCrS304H experienced the least amount of oxidation, followed by the CrS304H. The AlCrS304H appeared to display the worst oxidation behavior.

Concerns:

None.

Activities Next Quarter:

CrS304H, AlCrS304H and SiCrS304H specimens will be prepared for and entered into test at 900°C.

Task 3C Assessment of Temperature

Background:

Based on the steamside oxidation test results, the practical temperature limits for the materials tested will be determined.

Experimental:

Results from B&W and ORNL continue to be evaluated.

Concerns:

None.

Activities Next Quarter:

Activation energies will be re-calculated following the third 800°C exposure.

Task 3D Review of Available Information & Reporting

Background:

Available steamside oxidation literature pertaining to materials and environmental conditions of interest will be reviewed. Project status updates will be prepared and status meetings will be attended as required.

Experimental:

Monthly status reports were prepared for October and November, 2005. A Quarterly Report was prepared for July – September, 2005.

Concerns:

None.

Activities Next Quarter:

Monthly status reports will be written for January and February, 2006. A Quarterly Report will be written for October – December, 2005. A Steering Committee Meeting will be attended in Charlotte, NC.

Task 3E Conduct Experimental Exposures

Background:

The steam oxidation behavior of model Fe-Cr alloys will be evaluated.

Experimental:

B&W is remaining cognizant of the ORNL tests on these model alloys.

Concerns:

None.

Activities Next Quarter:

BWRC will maintain cognizance of ORNL results.

Task 3F Characterization

Background:

Samples of the model Fe-Cr alloys fabricated in Task 3E will be characterized before and after steamside oxidation testing using metallographic and electron optic techniques.

Experimental:

None.

Concerns

None.

Activities Next Quarter:

None.

Task 3G Data Analysis and Coordination

Background:

The steamside oxidation results will be evaluated to determine the effects of material properties and environmental factors on oxidation behavior.

Experimental:

No progress will be possible until the steamside oxidation tests have been completed (GFY2006).

Concerns:

None.

Activities Next Quarter:

None.

Milestone Chart:

Dates are listed in GFY.

Task 4

Fireside Corrosion

(Foster Wheeler)

The objective of the task is to evaluate the relative resistance of various advanced alloys for waterwall and reheater/superheater construction to fireside corrosion over the full temperature range expected for the USC plant. The corrosive environment promoted by three different coals, representative of an eastern coal, a midwestern coal, and a western coal, will be evaluated.

Task 4A: Laboratory Testing

Objective:

The objective of this sub-task is to perform laboratory corrosion tests on the candidate alloys. This will be accomplished by exposing metal coupons to various deposits and flue gases representative of three coals (e.g., eastern, midwestern, and western) at the range of temperatures expected for the USC plant.

Experimental Progress:

During the quarter, evaluation of the results of the laboratory tests on the samples exposed to waterwall conditions was performed. Photographs were taken comparing the post-test macroscopic appearance of the laboratory specimens of each alloy to the various test conditions – examples for alloy P92, SAVE 12, and HCM12A are shown in Figures 1, 2, and 3, respectively. Photographs were also taken comparing the macroscopic appearance of various alloy groups exposed to all three-test conditions. Figures 4 and 5, herein, illustrate the macroscopic appearance of various wrought and weld-overlay waterwall specimens exposed to Midwestern conditions. Graphs of wastage versus temperature were made for various wrought waterwall alloys for all three test conditions. Graphs were also made with the wastage results of the weld overlays superimposed in order to compare the performance of weld overlays against the wrought alloys. The graph comparing the wastage results of four wrought alloys (T23, Abe, P92, and HCM12A) to the 622, 52, and 72 weld overlays tested under Midwestern conditions is shown in Figure 6.

Figure 1

Macroscopic appearance of P92 specimens exposed in the waterwall laboratory corrosion tests is displayed.

Figure 2

Macroscopic appearance of SAVE12 specimens exposed in the waterwall laboratory corrosion tests is illustrated.

Figure 3

Macroscopic appearance of HCM12A specimens exposed in the waterwall laboratory corrosion tests is shown.

Figure 4

Comparison of the macroscopic appearance of the 9-12 Cr-Mo specimens exposed to Midwestern conditions in the waterwall laboratory corrosion tests is illustrated.

Figure 5

Comparison of the macroscopic appearance of the weld overlay (WO) and 50/50LC (laser clad) specimens exposed to Midwestern conditions in the laboratory corrosion tests is shown.

Figure 6

Graph of wastage versus temperature for four wrought alloys and three weld overlays is presented for waterwall specimens tested under Midwestern conditions.

Concerns:

None.

Plans for Next Quarter:

Continue to refine the results of the laboratory tests.

Task 4B Corrosion Probe Testing in Utility Boilers

Objective:

The objective of this sub-task is to install corrosion probes comprised of various alloys/coatings/weld overlays at three coal-fired power plants and control them in the temperature range expected for reheater/superheater components in the USC plant. The plants should burn coals representative of the three types specified earlier.

Experimental Progress:

- Fabrication and mechanical assembly of the probe retraction mechanisms for all three host sites have been tested.
- Data acquisition, instrumentation and control systems development has been completed and validation testing is under way.
- Assembled probes have been readied for shipment to host site, for exposures to begin in January 2006.
- Electrical and mechanical on-site work needed to accommodate the new installation is under way and will be completed January 2006.
- Material samples for the probes been machined and assembly of probes for the second host site has been completed.
- Critical components have been delivered to the first and second host sites.
- Foster Wheeler continues to work closely with the host utility personnel to coordinate installation activities.
- Changes in fuel at our original Eastern coal host site have necessitated locating a new host site. Discussions were held with a new plant in Ohio to replace the original third host site.

Concerns:

The original third host site has indicated that their fuel is being changed to 100% low-sulfur PRB coal. This requires finding a new host site, firing a different coal (possibly Eastern / PRB blend coal). Discussions are under way with AEP to locate another possible host site within Ohio.

Plans for Next Quarter:

- Complete mechanical and electrical modifications at all host sites.
- Finalize hosting arrangements and logistics for third host site.
- Complete the testing of instrumentation and controls systems for remaining probes.
- Complete final assembly of the remaining probes.
- Continue site installation tasks, coordinating with host utilities.
- Install probes at remaining host sites.
- Monitor exposures at all host sites.

Task 4C Steam Loop Design, Construction, and Testing

Objectives:

The objectives of this sub-task are to design, build, and test an experimental USC steam loops that will operate in a commercial boiler at metal temperatures up to 1400°F. The elements of this subtask include the following:

- Design and construct the test loop using commercially-available, high-temperature corrosion-resistant alloys selected for the USC Plant.
- Install and operate the test loop at the Reliant Electric power plant, which is located in Niles, OH and is burning high sulfur Ohio coal.
- Test and monitor the relative performance of the USC tube alloys, coatings, claddings, and weld overlays, which comprise the test loops, for a period of 18 to 24 months.

Experimental Progress:

After repair and replacement of the malfunctioning steam control valves and associated equipment, testing of the USC Test Loops at Niles resumed on August 24, 2005. On December 12, a controller for the steam valve on USC Test Loop A (with surface metal temperatures up to 1400°F) failed, and the system automatically reverted to maximum

steam cooling flow. With maximum cooling flow, the maximum surface temperature varies from about 800°F to 1000°F. Test Loop B (with metal temperatures up to 1280°F) is still functioning normally. The B&W systems design engineer stated that a new controller has been ordered for Loop A, and replacement will be made during the next unscheduled plant outage, if possible. However, current plans are to remove the loops during the next scheduled outage, tentatively planned by Reliant Energy for March/April of 2006. The management of the Niles facility is anxious to have the loops removed and that extending testing further into 2006 is out of the question. Following removal of the test loops, all equipment that was originally installed to operate the loops (sensors, controllers, attemperators, etc.) will be removed for site restoration. Metallurgical analysis of the loops will also begin around May or June 2006, and the results should be documented in a draft report by the fall of 2006.

Plans for Next Quarter:

- Continue to operate test loops in current condition until new controller for the steam valve on Loop A can be installed.
- Unless circumstances change removal of the loops may commence at the end of the quarter.

Task 5 Welding Development (Alstom)

Objectives:

- To define weld metal choices for candidate materials.
- To establish acceptable welding procedures and practices.
- To evaluate the effects of manufacturing heat treatments and preheat and post weld heat treatments on weldment integrity and properties.
- To produce samples needed to determine the properties of candidate ultrasupercritical alloy welds and weldments, including the dissimilar metal weld joints between the various types of material (the actual mechanical and property testing will be performed under Task 2).

These objectives will be accomplished through execution of five sub-tasks. Where activity on these sub-tasks occurred during the reporting period, it is described below.

Task 5B: Optimization of Weld Parameters

Objectives:

The primary objectives of this subtask are to establish the baseline welding parameter values for each material/process/product form combination being studied. Included is the development of preheat and post weld heat treatment requirements.

Progress for the Quarter:

SAVE 12:

- The SAVE12 heavy wall (13.78-inch OD x 2.3-inch wall pipe) weld qualification efforts continued with further investigation of flux core as a relatively high deposition fill process. Initial qualification attempts were unsuccessful because of failed bend tests. However, closer examination of the failed specimens revealed that preparation operations had introduced a thick layer of cold worked material on the machined surfaces. More careful preparation steps reduced the thickness of this layer and allowed a second set of specimens to meet the bend testing requirements and a formal welding procedure to be prepared. This procedure utilized a gas tungsten arc root, shielded metal arc intermediate passes, and flux core fill passes and was designated GTA/MA/FC/SAVE12-1.

- Although the thick-section welding process using a flux core fill was qualified, further metallurgical examination of the bend specimen surfaces and cross-sections revealed the existence of tungsten and neodymium inclusions and titanium, chromium and silicon oxides. Since these inclusions and metallic oxides are potentially detrimental to creep rupture properties, the fabrication of weld characterization specimens using the same lot of flux core filler that was used in procedure qualification was not considered advisable. Moreover, the discovery of these unusual inclusions and oxides prompted a return to the submerged arc process for fill passes because alternate lots of flux core material were not immediately available.
- The bare weld wire and submerged arc weld deposits made using WP380 flux were studied with regards to inclusions and their potentially detrimental effect on creep rupture properties. Detailed metallurgical examinations demonstrated that these deposits also contained tungsten and other nonmetallic inclusions and prompted considering modifications to the consumables. Discussions with the flux and wire vendors are currently underway regarding reformulations to address the inclusion issue.

Inconel 740:

- Hot wire gas tungsten arc welding tests were conducted on 2-inch thick Inconel 740 plates using a 25% Helium/75% Argon shielding gas and matching filler wire. Preliminary test results from two cross sections were encouraging in that, in spite of this being a thicker weld with higher restraint, there were very few microfissures compared to earlier samples using a pulsed gas metal arc process. Bend and tensile tests will be conducted for further evaluation of this plate in an attempt to fully qualify a welding procedure.
- Special Metals reported that their test program to study the effects of chemistry on microfissuring tendencies is progressing. They have found that lowering silicon and niobium levels tends to reduce microfissuring.

General

An outline for a final comprehensive Task 5 report was prepared and circulated among the task members for review. Agreement was reached on the general content and organization of the report and now preparation of the various sections can begin. The report will have an introduction giving the background for the task, a summary section organized to align with the subtasks, and a series of appendices containing all of the welding development details. The appendices will be organized by material, rather than subtask, so that each task member can work independently and address unique issues appropriately without having to be concerned with how something would be coordinated with the efforts of others.

Concerns:

- Submerged arc welding, a high deposition rate process favored by boilermakers for thick sections, does not appear feasible for all nickel base materials. Tests on Haynes 230 and Inconel 740 have been unsuccessful because of cracking and the process is being abandoned on these two alloys.
- The unexpectedly high cost of the nickel base alloys will cause the material budgets to be exceeded and might result in program cost overruns and/or reductions in program scope.
- The difficulties encountered while attempting to weld HR6W using matching filler metals proved insurmountable for this program and there will be no further effort in this area.
- Inconel 740 appears to have a heat-to-heat sensitivity with regards to microfissuring and this could require additional constraints on composition.
- The use of matching filler metal for welding thick section CCA 617 plates does not appear practical.

Plans for the Next Quarter:

- Continue with the efforts to qualify the welding of the SAVE 12 thick wall pipe material using a submerged arc process.
- Continue to study the problems with heat affected zone microfissuring in Inconel 740 by making hot wire gas tungsten arc welds in 3-inch thick plate.
- Continue preparation of final comprehensive report.

Task 5C: Preparation of Laboratory Samples

Objectives:

The primary objective of this subtask is to produce multiple samples representing each of the material/process/product form combinations being studied. These samples will be evaluated by ORNL as part of the Task 2 activities.

Progress for the Quarter:

Another set of butt weld samples in the 2-inch diameter, 0.4-inch minimum wall thickness SAVE 12 tubing was prepared and is currently being examined and heat treated before shipment to ORNL for testing. This set used a qualified manual gas tungsten arc process throughout and the SAVE 12 custom filler.

Concerns:

None.

Plans for the Next Quarter:

- Using a process that has already been qualified, provide ORNL with a P92 pipe (6.3-inch OD x 1.1-inch wall) butt joint sample for testing.

Task 5D Weldability Testing

Objectives:

The primary objective of this subtask is to investigate any major weldability problems that arose during the weld procedure development efforts of Subtask 5C. The advertised properties of Inconel 740 made it an attractive material for use in an ultrasupercritical boiler, however significant welding issues were encountered which necessitated fundamental weldability studies before procedure development could continue. Edison Welding Institute was commissioned to conduct these studies and four specific objectives were identified:

1. Evaluate the heat affected zone liquation cracking susceptibility of Inconel 740.
2. Evaluate the heat affected zone ductility dip cracking susceptibility of Inconel 740.
3. Evaluate the post weld heat treatment cracking susceptibility of Inconel 740 and make a comparison with other common nickel-based precipitation-hardening alloys such as Inconel 718 and Waspaloy.
4. Evaluate the mechanical properties of Gleeble-simulated heat affected zones in Inconel 740 and of Inconel 740 welded plate joints in the post weld heat treated condition.

Progress for the Quarter:

With regards to the four objectives:

The Edison Welding Institute issued a final report and the results were reviewed in detail with B&W personnel. The findings paralleled B&W's empirical data regarding the susceptibility of Inconel 740 to liquation cracking. However, the research data indicated that other possible problem areas, such as strain age cracking or ductility dip cracking, would not be prevalent in Inconel 740.

Concerns:

None.

Plans for the Next Quarter:

This activity is complete.

Task 5E: Examination of Dissimilar Metal Welds

Objectives:

The primary objectives of this subtask are to develop and study the dissimilar metal welds that would be required to make transitions between the various alloys included in this program and the conventional materials that would also be used in an ultrasupercritical boiler.

Progress for the Quarter:

Dissimilar metal weld samples involving SAVE 12 and HR6W tubing were prepared and sent to ORNL for evaluation. The butt welds in the 2-inch diameter, 0.4-inch minimum wall thickness tubes utilized a manual gas tungsten arc process with Inconel 82 filler for the root pass and shielded metal arc welding with INCO A electrodes for the fill passes.

Concerns:

None.

Plans for the Next Quarter:

Fabricate samples of dissimilar metal joints between the HR6W and SAVE12 tubing using only gas tungsten arc welding for testing by ORNL.

Task 5: Welding Development - Milestone Chart
(DOE Fiscal Year Basis)
(percentages indicate fraction of workscope completed as of 2005Q4)

Task	Milestone	Year 2002				Year 2003				Year 2004				Year 2005				Year 2006			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
5A	Selection of Weld Filler Material																				
	• Procure base metal for weld trials.	△						100%	▲												
	• Evaluation and selection of filler.		△					100%				▲									
	• Procurement of candidate fillers.		△					100%				▲									
5B	Optimization of Welding Parameters																				
	• Preliminary weld trials and parameter optimization – thin section.				△			95%												▲	
	• Preliminary weld trials and parameter optimization – thick section.				△			90%												▲	
5C	Preparation of Laboratory Samples																				
	• Material preparation.							△	90%												▲
	• Sample fabrication.							△	90%												▲
5D	Weldability Testing												△		100%					▲	
5E	Examination of Dissimilar Metal Welds.																				
	• Weld trials											△	60%								▲
	• Metallurgical analysis											△	0%								▲
	• Analysis and test case.											△	0%								▲

Task 6 Fabrication (B & W)

Objectives:

The objective of Task 6 is to establish boiler fabrication guidelines for the high temperature, oxidation and corrosion resistant alloys selected for the USC Project. The principal goals in this joint effort are:

- To establish fabrication guidelines for the high temperature, corrosion resistant alloys needed for boiler components in the USC power plant.
- To determine the thermomechanical treatments or other remedial actions necessary to restore material properties which might degrade due to fabrication operations.
- To investigate prototypical manufacturing operations for producing both thick wall and thin wall components from the USC alloys.

Progress for the Quarter: Riley Power, Inc.

Riley Power has continued the preparation of summary reports on the history and accomplishments of the materials fabricability efforts. The format established by B&W will be used for the content and assembly of the report.

Concerns:

None.

Plans for the Next Quarter:

- After the recrystallization study results are available, Riley Power will determine the appropriate heat treatments applicable to the HR6W and SAVE12 materials, and additional samples of the materials may be sent to ORNL for testing.
- Riley Power Inc. is still considering the fabrication of a mock-up header/spool piece which would contain tubing components and welding of the HR6W and SAVE12 materials.

Progress for the Quarter: Alstom Power, Inc.

U-bend Specimens

- Destructive examinations were continued.

Tapered Tube Specimens

- Metallurgical examination of the tapered tube specimens prepared for the cold working studies was continued.
- Sets of Super 304H and CCA617 samples were heated at 1600°F for 1, 10, and 100 hours and have been prepared for microstructural examination and hardness.

Concerns:

No new concerns.

Plans for the Next Quarter:

- Remake the 2-inch radius Super 304H hot bends.
- Complete destructive examination of U-bend specimens.
- Continue the examination of the tapered tubes used for the cold working studies.
- Determine the sensitivity of Super 304H to strain induced embrittlement.

Progress for the Quarter: Foster Wheeler

Fabrication of IN740:

- Performed microscopic examination and microhardness survey of the bends. The results of the microscopic examination are illustrated in the attached file. Figure 1 displays the microstructure in longitudinal sections of the original tube in both the hard and soft zones. The hardness of each zone is also indicated in the photomicrograph. Figures 2 through 4 show the microstructure in longitudinal sections removed from the center of the bend at both the extrados (top photomicrograph) and intrados (bottom photomicrograph) in the 3.38D (14.8%OFS), 2.5D (20%OFS), and 1.5D (33.3%OFS) bends, respectively. The hardness at each location is also indicated in the photomicrographs and summarized in the table below:

Bend (OFS)	Extrados	Intrados
3.38D (14.8%)	20HRC-226HB	27.5HRC-269HB
2.5D (20%)	24HRC-249HB	28.5HRC-274HB
1.5D (33.3%)	28.5HRC-274HB	31.5HRC-294HB

As expected, the hardness increased with increasing strain levels in the bend. In all three bends, the hardness at the intrados was higher than that at the extrados.

Recrystallization Studies

- Determine the strain level for the onset of recrystallization in the HR6W sample exposed to 1400°F/150 hours to be 18.8 percent. The data set for the four exposures on HR6W is as follows:

Temperature/Time	% Strain for Onset of Recrystallization
1400°F/150hrs	18.8
1500°F/100hrs	13.9
1600°F/100hrs	12.0
1600°F/1000hrs	9.0

Concerns:

None.

Plans for the Next Quarter:

- Plans for next quarter are to continue the analyses of strained and thermally exposed specimens and to assess the data for correlation based on the Larson-Miller parameter.

Progress for the Quarter: B&W

- Preparation of B&W's contribution to the Task 6 final topical report continued.
- Swaging trials with Alloy 230 tube specimens were completed at B&W's Cambridge manufacturing facility (see Figures 1 and 2).

Figure 1 Image showing 2" OD alloy 230 tube specimens that were machined with a 0.200" wall thickness and swaged to both 1.75" OD and to 1.5" OD. One 2" OD X 0.400" MW tube specimen was also successfully swaged to 1-7/8" OD.

Figure 2 Image showing 2" OD alloy 230 tube specimens that were swaged to 1.75" OD, annealed, and then swaged to 1.5" OD.

- Fabrication of Demonstration Article "A" (nested USC superheater loops) was completed (see Figure 3).

Figure 3 Completed Demonstration Article "A" (nested USC superheater loops) demonstrating developed fabrication procedures.

- A description of Demonstration Article "A" was prepared for EPRI and is provided below.

USC Demonstration Article Superheater Section Fabrication

Some of the fabrication processes that were developed in the Ultra Supercritical (USC) boiler Materials Project have been successfully demonstrated by the Babcock & Wilcox Company by constructing a model superheater section. The fabrication processes demonstrated included bending, forming, machining, boring, welding, and grinding. To produce the steam superheater loops for the demonstration article, three alloy 230 tube U-bends of different radii were initially produced in a boiler manufacturing plant and joined with straight tube lengths of other advanced, high-temperature alloys, including 740, CCA617, HR6W, and Super304H. Some of the tube lengths had protective weld overlays of alloys 52, 72, or 622 applied to their surfaces. The three completed steam loops were then configured in a "nested" arrangement to simulate the multiple loops of a USC superheater section. To complete the assembly, corrosion resistant attachments of 50Cr-50Ni were welded to the loops using commercial filler metals, and tube ends were machined with beveled weld preps. B&W is currently in the process of building a second USC demonstration article to display some of the fabricating processes that were also developed for the commercial manufacture of thick-wall USC headers.

- Fabrication of Demonstration Article "B" (thick-wall header assembly) was initiated.

Concerns:

None.

Plans for the Next Quarter:

- Preparation of B&W's contribution to the Task 6 final topical report will be completed.
- Fabrication of Demonstration Article "B" (thick wall header assembly) will be completed.

TABLE 6
Schedule and Progress

ID	Task Name	Start	Finish	Status	2001				2002				2003				2004				2005				2006				2007
					Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
1	Task 6: Fabricability	Tue 1/1/02	Tue 8/1/06	In Progress																									
2	6A: Fab Trials for SH	Tue 1/1/02	Fri 3/10/06	In Progress																									
3	6A.1 SH Trial	Tue 1/1/02	Mon 10/10/05	Complete																									
4	Procure Materials	Wed 1/2/02	Fri 5/30/03	Complete																									
5	Shop Sched & Graphics	Tue 4/1/03	Mon 6/2/03	Complete																									
6	Travel to Shop	Mon 6/2/03	Mon 10/10/05	Complete																									
7	Cold Bending Trials	Mon 6/2/03	Fri 3/10/06	In Progress																									
8	Cold Swaging Trials	Mon 6/2/03	Fri 3/10/06	In Progress																									
9	Butt Welding Trials	Mon 6/2/03	Fri 6/4/04	Complete																									
10	Attachment Welding Trials	Mon 6/2/03	Fri 8/6/04	Complete																									
11	6A.2 Reporting	Fri 1/3/03	Tue 8/1/06	In Progress																									
12	6A.3 SH: Met Test & Eval	Fri 1/9/04	Mon 10/10/05	Complete																									
13	6A.3.1 Mic Bends&Welds	Fri 6/4/04	Mon 10/10/05	Complete																									
14	6A.3.2 HT Studies&Mic	Fri 6/4/04	Fri 1/27/06	In Progress																									
15	6B: Fab Thk Wall Comp	Fri 1/9/04	Tue 8/1/06	In Progress																									
16	6B.1 Thick-Wall Fab Trial	Fri 1/9/04	Fri 3/10/06	In Progress																									
17	6B.2 Reporting	Fri 1/9/04	Tue 8/1/06	In Progress																									
18	6B.3 Thick-Wall Comp	Fri 1/9/04	Fri 3/10/06	In Progress																									
19	6B.3.1 Met Analysis	Wed 6/29/05	Tue 11/15/05	Complete																									
20	6B.3.2 PVHT Studies&Mic	Wed 9/29/04	Thu 10/6/05	Complete																									

Task 7 Coatings (Alstom)

Objectives for Task 7 Coatings:

- Review state-of-the-art of coating technology and identify development needs.
- Develop coating manufacturing techniques, which can provide corrosion/erosion protection for components in USC boilers, cost effectively.
- Establish manufacturing techniques for application of internal coatings for oxidation protection, cost effectively.
- Provide coated samples for corrosion and oxidation testing in the laboratory and “in the field”.

These objectives will be accomplished through execution of eight sub-tasks. Where activity on these sub-tasks occurred during the reporting period, it is described below.

Task 7G: Manufacturing Guidelines

Objective:

Investigate the requirements for production coating of boiler materials.

Progress for the Quarter:

Work efforts for this task have concentrated on the requirements for diffusion-coating of the internal surface of boiler tubing. An economic evaluation was completed to determine the costs involved in setting up a processing operation. Editing of a report on this subtask was started.

Concerns:

None.

Activities Planned for Next Quarter:

Issue a report of the manufacturing requirements and costs for coating of internal tube surfaces.

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Task Name	Status	2002				2003				2004				2005				2006					
		Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	
Task 7: Coatings																							
Task 7A: Detailed Study of Current State of the Art																							
Alstom Task 7A: Detailed Study of Current State of the Art	Complete																						
Task 7B: Coating Feasibility (Internal Coating)																							
Alstom Task 7B: Coating Feasibility (Internal Coating)	Complete																						
Task 7C: Coating Recommendations																							
Alstom Task 7C: Coating Recommendations	20%																						
Task 7D: Laboratory Testing																							
Alstom Task 7D: Laboratory Testing	Complete																						
Task 7E: Process Scale Up - Preliminary Trials																							
Alstom Task 7E: Process Scale Up - Preliminary Trials	Complete																						
B&W Task 7E: Process Scale Up - Preliminary Trials	Complete																						
Task 7F: Process Optimization																							
Alstom Task 7F: Process Optimization	Complete																						
B&W Task 7F: Process Optimization	Complete																						
Task 7G: Manufacturing Recommendations																							
Alstom Task 7G: Manufacturing Recommendations	95%																						
B&W Task 7G: Manufacturing Recommendations																							
Task 7H: Specimens for Field Corrosion/Oxidation																							
Alstom Task 7H: Specimens for Field Corrosion/Oxidation	Complete																						
B&W Task 7H: Specimens for Field Corrosion/Oxidation	Complete																						
Task 7I: Project Management																							
Alstom Task 7I: Project Management	Ongoing																						
B&W Task 7I: Project Management	Ongoing																						

Scope Accomplished Versus Actual Expenditures Task 7 Coatings Alstom Scope

Task 8 Design Methods and Data (Alstom)

The major objectives for Task 8 are:

- Review the methods used by Section I of the ASME Boiler and Pressure Vessel Code to utilize materials properties and behavior models in the design of ultra-supercritical boilers.
- Develop and document methodologies whereby the results of the other tasks within this program may be most effectively applied within the ASME Section I design environment.
- Pursue the incorporation of such methodologies into Section I.

These objectives will be accomplished through execution of seven sub-tasks. Where activity on these sub-tasks occurred during the reporting period, it is described below.

Task 8A: Task Management (ALSTOM)

Objective:

The primary objective of this subtask is the overall management of the task, coordinating meetings and preparing progress reports.

Progress for the Quarter:

Progress continued to be rather slow. Limited material data availability and resource issues continue to hamper progress, however, during the period, ALSTOM allocated additional resources to ensure completion of project goals.

Concerns:

None.

Plans for the Next Quarter:

Continue general task management activities.

Task 8B: Material Data Collation and Processing (FW)

Objective:

The creation of documentation to ensure that quality test data is transferred between tasks and that this data remains traceable. A second objective is the analysis of such data with the objective of improving the statistical correlation. Foster Wheeler is subtask leader, with Riley Power Inc. providing significant input to this subtask.

Deliverables:

Item	Responsible	Status
Material data transfer sheets	ALSTOM	Transfer sheets provided for creep and tensile tests.
Electronic data repository	ORNL	Website complete.
Recommendations for statistical analysis of data		
Data compendia and fits for key materials		
Code case packages and submissions to code committees	ALL	

Progress for the Quarter:

Riley Power Inc. has continued to monitor the USC data transfer website for any added completed test results for the HR6W and SAVE 12 materials, assigned to Riley. Currently for HR6W, the only missing results are for metallography. Also to date, the only completed test results for SAVE12, posted on the website, are for chemical composition of the base material and weld filler metals. Riley has also continued to generate a summary report of the test results for HR6W, including percent creep strain and stress versus time to rupture plots for the test specimen and weldment results. The test results have also been compared to calculated stress versus time to rupture values, using creep rupture and Larson-Miller data from the Sumitomo document dated, February 2004.

ALSTOM Power Inc. reviewed data on the USC data transfer site for CCA617 and Super304H. No base metal creep or cross weld creep data was added in the quarter so no additional material evaluation was possible. In addition, no data appear to have been added for IN740.

Concerns:

None.

Plans for the Next Quarter:

The task participants will continue to monitor the USC data transfer web site for any additional, completed test results. Evaluations will continue to compare and contrast the strength of the materials with existing databases for similar alloys. Riley will complete the summary report of the test results for the HR6W material. It is projected that it will not be possible to work on statistical correlation of data for some time because of the lack of data on which to perform meaningful analysis. Support will be provided to Task 2, as needed, to address issues with additional structural feature tests, or interpretation of existing tests.

Task 8E: Continuum Damage Mechanics (B&W)

Objectives:

The objective of this subtask is to analyze uniaxial and multiaxial creep test data from Task 2 for several (three) materials to:

- establish the continuum damage mechanics (CDM) parameters,
- evaluate multi-axial strength theories and failure criteria,
- assess the implications of cyclic creep for USC materials,
- evaluate and compare CDM, reference stress and Omega models of typical ASME geometries.

Progress for the Quarter:

The continued scarcity of long-term creep data for the candidate materials means that the effort to model the creep response with continuum damage mechanics or other models remains on hold. Furthermore limited multiaxial creep rupture data are available (one notch bar test for IN740) so determination of the multiaxial stress rupture criterion cannot proceed.

Thermal cycling tests continue at ORNL but ALSTOM has yet to obtain details of the tests to allow modeling and interpretation of the results.

The study to assess the cycling capability and margins against shakedown and ratcheting for a typical segment from a superheater header, which was completed last quarter, was formatted into a topical report and awaits final internal review by ALSTOM prior to a draft being sent to other project participants.

Concerns:

Timely availability of creep data on ORNL web site and results of notched bar creep rupture tests.

Plans for the Next Quarter:

Monitor material data web site to see if sufficient data is available to initiate a modeling activity. Check on status of structural feature tests. Issue topical report on the study comparing cycling capability of candidate alloys.

Task 8F: Weld Analysis and Assessment (ALSTOM)**Objective:**

Create simplified analysis models of welds and heat affected zones (HAZ) utilizing material properties obtained from the open literature and from Task 2 to permit accurate creep life assessment of weldments.

Deliverables:

Item	Responsible	Status
Topical review of weld analysis and assessment in creep range.	ALSTOM & RPI	In progress.
Collation of material data for weld metal and HAZ.	RPI	In progress.
Creep models for weld metal and HAZ regions.	ALSTOM	In progress.
Report documenting the simulation of welded specimens and common Code geometries.	ALSTOM	
Report documenting the development and use of approximate weld assessment methods.	ALL	

Progress for the Quarter:

Riley Power Inc. has previously submitted their contribution to the weld literature review and awaits ALSTOM's contribution so that a complete document can be reviewed, edited necessary and issued to the project team.

ALSTOM allocated new resources to complete the weld literature review and made some progress during the quarter. Specifically, a number of papers documenting design and life assessment methods were reviewed and assessed. A number of simple models were also analyzed to evaluate different methods for weld assessment. Based on the content of the portion of the literature review provided by Riley Power, and the recent evaluation of assessment methods, a reference stress based method of weld evaluation appears attractive. The method handles material strength mismatches with minimal material data, it can capture constraint effects due to weld geometry and it can capture the overall effects of geometry and loading of the weld. Further trials with this technique continue to evaluate its potential.

Concerns:

None.

Plans for the Next Quarter

In the next quarter, ALSTOM will complete their portion of the weld literature review and work with Riley Power to issue the weld literature review summary report. Also, the weld creep rupture test data for nickel-based alloys will be compared and contrasted to help guide future modeling efforts.

Task 8G: Basic Design Rules for Cylinders (ALSTOM)

Objectives:

Review the various equations used by the ASME Code, Section I for Power Boilers to define the minimum thickness of cylinders under internal pressure and develop a single methodology applicable to ultrasupercritical boilers.

Deliverables:

Item	Responsible	Status
Report summarizing existing approaches and comparing and contrasting their predictions	ALSTOM	Complete (Aug 2003)
Report recommending a single equation with supporting theoretical data.	ALSTOM	Complete (Sept 2003)
Code case submission	ALSTOM	Complete (October 2003)

Progress for the Quarter:

No activity for this quarter.

Concerns:

None.

Plans for the Next Quarter:

None.

Task 9

Project Integration and Management (EPRI)

- The objective of Task 9 is to coordinate the project and provide reporting to DOE and Ohio Coal Development Office (OCDO).

Progress for the Quarter:

- Completed fourth Quarterly Report for 2005.
- Completed Monthly Reports for October and November, 2005.
- Monthly conference calls were held and the discussions were documented.
- Presented an overview keynote speech at the Super-High Strength Steels conference in Rome, Italy on November 2, 2005.

Concerns:

- None

Plans for the Next Quarter:

- Issue monthly reports and hold conference calls as required.
- Conduct Steering Committee Meeting in Charlotte on January 18th and 19th, 2006 and provide minutes.