BOILER MATERIALS FOR ULTRASUPERCRITICAL COAL POWER PLANTS

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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). The project goal initially was to assess/develop materials technology that will enable achieving turbine throttle steam conditions of 760°C (1400°F)/35 MPa (5000 psi), although this goal for the main steam temperature had to be revised down to 732°C (1350°F), based on a preliminary assessment of material capabilities. The project is 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 July 1 to September 30, 2004.

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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, and DOE's Vision 21. 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

- The last laboratory corrosion test was completed. Samples are currently being evaluated.
- Proposed amendments to ASME Section 1 for new reference stress calculation formula that will result in thinner tubing was accepted.
- A low-cycle fatigue test was started to evaluate CCA617's creep-fatigue behavior.
- A new ram was installed on a servo-hydraulic machine for thermal fatigue testing.
- 617 filler metal over-matches HR6W creep strength.
- Ac1 temperature of SAVE12 was determined to be around 820°C..
- Inconel 740 was found to not be a notch sensitive material.
- The induction equipment has been corrected on the thermal cycle testing machine.
- The second steamside oxide exposure at 800°C was started and three new alloys were added (NF709, Super 304H, and 347HFG).

- Welding qualifications were passed for SAVE12 tubing after an extended post weld heat treatment (PWHT).
- Testing has been completed and Inconel 740 has been found to not be susceptible to post weld heat treatment cracking.
- Thermal exposures were performed for three materials for recrystallization studies. Analysis is underway.
- ID Diffusion layers of adequate thickness and composition can be achieved provided the tubing pieces are end-capped during the diffusion process.

E. Plans for the Next Quarter

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

- Begin creep rupture testing of 2" thick CCA617 plate.
- Establish a weld metal chemistry for submerged arc welding of SAVE12 and determine lower critical transformation temperature.
- Determine efforts required to develop a gas metal arc welding (BMAW) procedure to make butt joints in Super 304H tubing.

F. Issues

- Slow release of funds from DOE has impacted the schedule of several tasks.
- High machining costs for specimens may limit the amount of thick section testing.
- Thick submerged arc welds (SAW) in SAVE12 have not been successfully qualified due to the formation of martensite. This is because of chemistry of the weld metal and changes of the lower critical transformation temperature.
- Availability of data from ORNL has impacted Task 8 schedule.

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:

Two presentations were made by Task 2 this quarter. They were.

- Q. Wu, J. P. Shingledecker, R.W. Swindeman, and V. K. Vasudevan. "The Precipitation Behaviors of Inconel 740 and Super 304H for Ultra Supercritical Conditions." 2005 TMS Annual Meeting & Exhibition, February 13-17, 2005, San Francisco, CA.
- Q. Wu, J. P. Shingledecker, R.W. Swindeman, and V. K. Vasudevan. "Microstructural Study of Nickel-base Superalloys for Ultra Supercritical (USC) Coal Power Plants" 2005 TMS Annual Meeting & Exhibition, February 13-17, 2005, San Francisco, CA.

Task 2B: Detailed Test Plan

Progress:

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.

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). 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. Weldment test plans for HR6W, Super 304H, and CCA617 butt welded tubes have been produced. Thick section weldments plans are being produced as welded material becomes available. A test matrix for verifying the fatigue and creep-fatigue behavior of CCA617 has been designed and testing initiated. Discussions with Task 8 members have helped define the structural tests needed by the boiler manufactures to evaluate their respective component models. Notched bar test plans for Inconel 740 have been produced to evaluate the materials notch sensitivity and multi-axial creep behavior.

TABLE 1. Compositions of USC Steam Boiler Consortium Materials															
Alloy	Nominal Compositions in Wt%														
	Fe	Cr	Ni	Mn	Mo	Ti	Nb	W	V	C	B	Si	N	Cu	Other
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:

Results indicate that the strength of the Super 304H and alloy 230 are meeting expectations, while the HR6W is below expectations. As previously discussed, Sumitomo believes the poor creep strength is due to low W in the consortium heat, but, based on the chemistry supplied by Sumitomo, the W level is well within the specification. The CCA617 alloy is exceeding expectations in the lower temperature regime (650°C to 700°C), based on performance equivalent to alloy 617. Larson-Miller-Parameter extrapolation shows the creep strength benefit may extend to 730°C for CCA617 vs. std. 617. Additional short-term tests have been added to the CCA617 test matrix. All of the planned Super 304H and HR6W creep-rupture tests are in progress. Testing is also progressing on the INCONEL 740 tubing. 100 and 1000 hours rupture lives appear close to predictions based off previous work at ORNL and data from Special Metals.

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 (UC) has been tasked with the metallurgical characterization of the USC materials (excluding the SAVE12). The characterization work at the UC includes: microhardness, optical microscopy, scanning electron microscopy (SEM) with elemental analysis by energy dispersive spectroscopy (EDS), and transmission electron microscopy (TEM). Short-term aging is being done on the USC materials at the UC in addition to longer-term aging at ORNL. Creep-tested specimens have also been analyzed. The goal of the aging is to understand the microstructural evolution of the USC materials at temperatures encountered during service in a boiler. The creep-tested specimens will be used to understand differences in microstructural evolution compared to aging without stress and how dislocations interact with precipitates and other microstructural elements.

This quarter, the gamma prime (γ') precipitates in Inconel 740 were studied after aging for various times and temperatures. As shown in the figure below, the coarsening of the gamma prime precipitates showed a linear relationship with time for the LSW coarsening law (precipitate diameter cubed) at 700 and 750°C. However, non-linear behavior was observed at 800°C after 3,000 hours. The apparent change in coarsening

behavior may be related to the more rapid formation of eta phase at 800°C. Aging is currently underway for 10,000 hours and beyond to complete the analysis.

Gamma Prime precipitate diameter cubed versus aging time at 700, 750, and 800°C for Inconel 740. A linear relationship is observed at 700°C and 750°C, but not 800°C.

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:

Testing continued on CCA617 this quarter to verify its properties relative to the 617 database. The continuous cycle tests to date appear to correlate well with the published fatigue data on standard 617 at 750°C. A low-cycle-fatigue test with a hold time was started this month to evaluate the material's creep-fatigue behavior. The test conditions were: temperature = 750°C, strain range = 0.7%, loading rate = .001/sec, hold time = 360 sec. The expected life for the test is 400 cycles.

A new ram was installed on a servo-hydraulic machine for thermal fatigue testing. The ram has checked out, but the induction heating unit has not. Once the induction heating unit is operational and all relevant safety equipment has been installed, thermal fatigue testing will begin.

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:

Creep-rupture testing continues on Haynes ® 230 plate weldments. The tests include: cross-weldments, parallel weldments, and weld-metal-only tests. Initial results show that the tube weldments are slightly weaker than the plate weldments. Testing also continues on butt-welded tubes of HR6W with 617 filler and 82 filler. Initial rupture locations are shown in the figures below. For the 82 welds, the rupture location was the base metal of the HR6W away from the weld. In contrast, the rupture in the 617 weldment initiated at the fusion line of the weld and propagated through the HR6W base metal. This indicates that 617 weld metal 'over-matches' the HR6W. The high degree of constraint imposed by the 617 weldment may reduce the creep-rupture life of the HR6W. Specimens from Super 304H and CCA617 tube weldments and dissimilar metal tube welds between the two alloys have been machined. Large cross-weld specimens from the CCA617 2" thick plate are being machined and testing will begin next month.

Post-Test Fractures for HR6W Tube Weldments

A small study into the critical temperatures of SAVE12 and SAVE12 weld metal is being conducted at ORNL. These results will help boiler manufacturers set the proper PWHT temperatures for the alloy. Some of the initial results obtained this quarter are shown below. Gleeble tests run at a heating rate of 2°C/min closely simulate the A1 temperature. Based on the initial analysis of the data, it appears the base metal's A1 temperature is between 810 and 820°C. The predicted A1 temperature for the base metal, from a neural network model developed at ORNL, is 820°C, which is in good agreement with the experimental results. More rigorous analyses of the data continue. These preliminary results suggest 800°C is a safe PWHT limit for SAVE12.

Gleeble Plot for two heating rates on SAVE12 base material (Mike Santella – ORNL)

Material Identification	Predicted A1, °C (°F)
SAVE12 Heat No W310507	820 (1508)
Weld Filler SAVE12 FC-S, Lot 20-1	809 (1488)
Weld Filler SAVE12 MC-T, Lot 50-1	819 (1506)
Weld Filler SAVE12 FC-G, Lot 43-1	826 (1518)
Weld Filler SAVE12 E14, Lot 126-1	826 (1518)
Weld Filler SAVE12 E12, Lot 126-1	826 (1518)

Predicted A1 temperatures for SVE12 base material and filler metals (Mike Santella – ORNL)

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, continues on two Haynes 230 bends and one HR6W bend. The test temperature was set at 775°C. It was agreed, through discussions with Task 8, that this temperature would be aggressive enough to produce recrystallization during the tests while keeping the pressures within safety limits. The internal pressure was set to produce rupture in 24,000 hours; based off the current ASME Section I formula for tubes. The tubes were measured using a CMM (Coordinate Measuring Machine) before testing. The tubes were removed after 1,000 hours and after 3,000 hours (total test time) and measured. The specimens have now exceeded to 7,000 hours total test time and will be removed at 8,000 hours. Inconel 740 tube bends are expected next quarter and will be prepared for testing.

Notched bar creep-rupture testing on the deeply notched 740 specimen continues past 4,000 hours. The diameter change is measured in the notch using a specialized diametral extensometer. The plot of this extensometer is shown below, and it appears the rate of creep deformation in the notch region is increasing. The long duration of the test indicates that Inconel 740 is not a notch sensitive material.

Problems encountered with the induction heating unit for the thermal shock testing have been fixed. A number of thermal cycles have been run using the machine and temperature gradients above 300°C are possible through the 0.4" wall thickness of a CCA617 tube. Some electrical noise, due to a grounding problem in the data acquisition system or from the induction heating unit, has been encountered in some thermocouples. Once this is fixed, thermal shock testing can continue.

Concerns:

The high machining costs for thick section weldments specimens may limit the amount of thick section testing. One option being explored to the reducing machining costs is to section the weldments before shipment from the boiler manufactures to ORNL – where overhead costs for machining are high.

Plans for Next Quarter:

The website will be updated with the most recent creep data and micrographs. Uniaxial creep-rupture tests on base metal will be extended to Inconel 740 plate specimens. Test plans for some tube weldments will be completed. Further microstructural evaluation of the aged, tensile tested, and creep tested Inconel 740 will continue with emphasis on the formation and growth of eta phase. Rupture testing on the CCA617 thick welded plate and the CCA617 and Super 304H tube butt weldments should begin. Inconel 740 tube bends are expected to be received and specimen preparation for

pressurized creep testing will begin. Creep-fatigue testing will continue on CCA617. Thermal-mechanical fatigue testing will also begin. The PWHT study on SAVE12 will be completed.

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, preparations were made to begin the second 1,000 hour exposure at 800°C, and the exposure was started. The first exposure at 800°C was completed in April of 2004. Due to funding constraints, additional testing was not possible during the remainder of 2004. The test rack with the specimens that had not been removed following the first 800°C exposure was kept in a desiccator during the past year. With funding being released in early 2005, preparations for the next test exposure were initiated.

Three additional materials were added for the second 800°C exposure. In October 2004, BWRC received a piece of AL20-25+Nb (NF709) from Foster Wheeler, and in January, BWRC received sections of 2" OD SUPER 304H and 347HFG tubing from Sumitomo. The results of independent chemical analyses performed on these materials are shown in Table 1.

TABLE 1

CHEMICAL COMPOSITION OF TEST MATERIALS												
Material	C	Si	Mn	Fe	Cr	Ni	Mo	W	V	Nb	N	Other
Tube 347HFG	0.082	0.39	1.59	Bal	18.41	11.59	0.27	0.001	0.047	0.92	0.054	0.26 Cu, 0.22 Co
Tube SUPER 304H	0.084	0.22	0.84	Bal	18.26	8.62	0.51	0.049	0.055	0.53	0.098	2.89 Cu, 0.15 Co
20-25+Nb (NF709)	0.074	0.44	1.02	Bal	20.47	25.52	1.49	0.086	0.13	0.34	0.094	0.23 Cu, 0.22 Al, 0.14 Co

In addition, SUPER 304H and 347HFG with a shot blasted ID surface was ordered from Sumitomo. The shot blasted material (due to arrive in April, 2005) will be included in the final exposure at 800°C. A comparison of the shot blasted and non-shot blasted specimens will provide a clear indication of the benefits that shot blasting provides with

respect to steam oxidation. For this reason, the specimens prepared from the SUPER 340H and 347HFG were machined such that the original ID surface was left intact. Surface area calculations were adjusted accordingly.

Four specimens were prepared from each of the three new materials. After machining, these specimens were measured, cleaned, weighed and wired onto the test rack with the remaining specimens that had been exposed to the first 1,000 hour exposure at 800°C. Two of these specimens will be removed and evaluated following the second exposure at 800°C. The remaining two specimens from each material will be removed after the final 800°C exposure. Figure 1 shows the test rack after the new specimens were attached. A list of all of the test material that were included in the second 800°C test run are shown in Table 2.

Figure 1. Test rack prior to second exposure at 800°C

Table 2

SPECIMEN MATERIALS AND NUMBER OF SPECIMENS FOR SECOND EXPOSURE AT 800°C (1472°F)	
P92 (F) – 2	VM12 (F) – 4
230 (A) – 4	214 (A) – 4
HR-120 (A) – 4	310HCbN (A) – 4
SAVE 25 (A) – 4	347HFG (A) – 4
CCA 617 (A) – 4	Cr-S304H – 4
SUPER 304H (A) – 4	AlCr-S304H – 4
Alloy 740 (A) – 4	SiCr-S304H – 4
HR6W (A) – 4	Mod. 740 (A) – 2
SAVE 12 (F) – 4	Tube 347HFG - 4
304H (A) – 4	Tube SUPER 304H - 4
T23 (F) – 2	20-25+Nb - 4
Abe (F) – 4	

The test facility and feedtanks were prepared for the next exposure, the test rack was placed inside of the retort, the retort was evacuated and backfilled with argon, the furnace was heated to the proper temperature, and test solution was pumped to the test facility. The second exposure at 800°C was started on March 17, 2005. On March 20, a power outage occurred that lasted ~4 hours. During the power outage, the flow of test solution was stopped and argon was flowed through the retort. When power was re-established, the temperature within the retort had dropped 400-500°F. Once the furnace had been restored to the proper temperature, solution flow was re-established.

It is anticipated that the second exposure at 800°C will be completed in early May

Concerns:

None.

Activities Next Quarter

The shot blasted tubing from Sumitomo will be received and specimens will be prepared. The second 800°C exposure will be completed. Specimens will be removed from the test rack and evaluated. The shot blasted specimens will be attached to the test rack and the final 800°C exposure will be started.

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 chromized specimens provided by Alstom (CrS304H, AlCrS304H and SiCrS304H) that were not removed from the test rack following the first 1,000 hour exposure are currently being tested in the second 800°C test.

Concerns:

None.

Activities Next Quarter:

The specimens removed following the second 800°C exposure will be evaluated. The remaining specimens will be tested in the final exposure at 800°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:

Additional progress will be made as test results become available.

Concerns:

None.

Activities Next Quarter:

Activation energy plots will be updated as the data from the second exposure at 800°C becomes available.

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 January and February, 2005. The Quarterly report for October – December, 2004 was prepared

Concerns:

None.

Activities Next Quarter:

Monthly status reports will be written for April and May. The Quarterly report for the January - March, 2005 timeframe will be prepared.

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. ORNL provided BWRC with 2 post-test metallographic mounts. BWRC will attempt to make measurements on these mounts using the same procedures used at ORNL.

Concerns:

None.

Activities Next Quarter:

The ORNL mounts will be measured and the results will be compared to the 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.

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

Objectives:

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:

The last 100-hour cycle of the 1400°F tests was completed. The final series of laboratory testing, which is at 1600°F, was also started and completed at the end of the quarter. (Note: The deposit and flue gas compositions, representing Eastern, Midwestern, and Western fuels, used in the tests were reported in the January – March 2004 Quarterly report.) This completes testing for all five temperatures for superheater/reheater conditions and for all three temperatures for waterwall testing.

The post-test analysis of the 1400°F superheater/reheater was started. Preliminary wastage results (i.e., metal loss plus subsurface oxidation/sulfidation) in 1000 hours are shown in Figures 1. [Note: The microscopic examination of the specimens for carburization has not been completed.] Since protective coatings may be necessary to mitigate OD wall loss caused by corrosion from the environment, the performance of the weld overlays, laser clad, and diffusion coatings in the laboratory tests is an important issue. Figures 2 through 4 illustrate the surface condition of the coatings tested after the 1000 hour exposure at 1400°F. [Note: The surface of the samples that were tested under Midwestern conditions, which are the most aggressive, are shown.]

In the laboratory tests performed at 1500°F, specimens containing higher Mo contents experienced greater attack, particularly under Midwestern conditions. To determine if the same behavior occurred at 1400°F, the CCA617 (9Mo) and Nim263 (5.8Mo) samples were examined after the 1000-hour exposure. While both samples displayed subsurface attack as shown in Figure 5, they did not exhibit the significant corrosion that was evident at 1500°F; however, the depth of corrosion was still greater than that in the

samples with lower Mo levels tested at 1400°F. Also, supporting this contention, Figure 6 illustrates the surface condition of the 230 (1.3Mo), 740 (0.5Mo), and HR3C (0Mo) samples exposed at 1400°F under Eastern, Midwestern, and Midwestern conditions, respectively. The 230 and 740 samples displayed notable subsurface attack, whereas the HR3C exhibited only minor subsurface corrosion.

Photomicrographs of the cleaned post-test superheater/reheater specimens (including the 1600°F samples) of selected alloys were taken to illustrate the effect of temperature and deposit/gas conditions on the macroscopic nature of the corrosion morphology. The photomicrographs, which are shown in Figures 7 through 11 for 230, CCA617, 740, HR6W, and HR3C, respectively, provide a thumbnail illustration of the alloy performance over the range of test conditions. [Note: It is anticipated that a similar macro-photographic summary will be prepared at the end of the laboratory testing for each alloy at all test conditions.]

With regard to the superheater/reheater testing at 1200°, 1300°, 1400°, and 1500°F, the following general comments can be made:

- As expected, specimens tested under Midwestern and Eastern conditions exhibited more wastage than those tested under Western conditions.
- For wrought alloys, the wastage decreased as the chromium level increased. In the absence of the Mo effect (in the 1400° and 1500°F specimens), the wastage tended to level off for alloys in the 22-27 Cr range, and the specimens tested at 1200° and 1300° displayed more surface attack than those tested at 1400° and 1500°F.
- At 1500°F under Midwestern conditions, the Mo-containing alloys experienced more attack than the alloys without Mo; the higher the Mo, the greater the wastage. Although not as prominent, the same trend was evident at 1400°F for Mo-containing alloys.
- Of the weld overlays, 72 (typically 42Cr) and 52 (typically 28Cr) performed better than 622 (typically 21Cr) at all temperatures, with 72 performing better than 52. At 1200° and 1300°F, the 72 and 52 were better than the wrought alloys in the 22-27 Cr range, while at 1400° and 1500°F they were only slightly better. At 1400° and 1500°F, the 622 overlay exhibited significant metal wastage.
- With regard to the diffusion coatings (on Super 304H), the FeCr and SiCr coatings performed better than the AlCr coating, which exhibited extensive subsurface attack at all test temperatures. The FeCr and SiCr coatings were comparable to the weld overlays, but because they are thinner will be breached sooner.

Concerns:

No concerns at this time.

Plans for Next Quarter:

Evaluate the samples exposed for 1000 hours at 1600°F.

Figure 1: Preliminary results of the Total Metal Wastage (wall loss plus subsurface penetration) of the 1300°F

Figure 2: The morphology of subsurface attack in the 52 (top) and 622 (bottom) overlays tested under Midwestern conditions at 1400°F for 1000 hours is illustrated.

Figure 3: The microscopic appearance of the subsurface attack in the 72 weld overlay (top) and the 50/50 laser-clad (bottom) specimens tested under Midwestern conditions at 1400°F for 1000 hours is displayed.

Figure 4: The surface condition of the FeCr (top), AlCr (middle), and SiCr (bottom) Diffusion coatings is shown after testing under Midwestern conditions at 1400°F for 100 hours. The AlCr coating suffered extensive subsurface attack.

Figure 5: The morphology of subsurface attack in the CCA617 (top) and Nim263 (bottom) Specimens tested under Midwestern conditions at 1400°F for 1000 hours is depicted. While both specimens experience subsurface attack, neither exhibited the significant corrosion that was evident at 1500°F under Midwestern conditions.

Figure 6: The microscopic appearance of the surface of 230 (top), 740 (middle), and HR3C (bottom) specimens tested under the Eastern, Midwestern, and Midwestern conditions, respectively at 1400°F for 1000 hours is shown. The 230 and 740 specimens exhibited notable attack compared to the HR3C specimen.

Figure 7: The post-test, cleaned appearance of the 230 superheater/reheater specimens illustrate the macroscopic nature of attack experienced under the various test conditions.

Figure 8: The post-test, cleaned appearance of the CCA617 superheater/reheater specimens display the macroscopic nature of attack experienced under the various test conditions.

Figure 9: The post-test, cleaned appearance of the 740 superheater/reheater specimens depict the macroscopic nature of attack experienced under the various test conditions.

Figure 10: The post-test, cleaned appearance of the HR6W superheater/reheater specimens highlight the macroscopic nature of attack experienced under the various test conditions.

Figure 11: The post-test, cleaned appearance of the HR3C superheater/reheater specimens illustrate the macroscopic nature of attack experienced under the various test conditions.

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:

- Funding for the construction and deployment of the corrosion probes for the third host site was made available.
- Fabrication and mechanical assembly of the probe retraction mechanisms for the third site have been started. Development of the data acquisition, instrumentation and control systems for all sites has continued, and been expanded to cover the third site.
- The two plants that were selected for the initial installations were Cinergy Gibson Generating Station (Indiana) and Xcel Energy Pawnee Station (Colorado). Gibson is firing a high-sulfur Farmersburg coal, while Pawnee is firing a low-sulfur PRB (e.g., Eagle Butte) coal. The third host plant selected is First Energy's Burger Station (Ohio), firing a high-sulfur bituminous coal.
- Material samples for the probes been machined and final assembly of probes for Cinergy's Gibson plant is under way.
- Critical components have been delivered to the Gibson and Pawnee sites.
- Foster Wheeler continues to work closely with the host utility personnel to coordinate installation activities.

Concerns:

None.

Plans for Next Quarter:

- Finalize hosting arrangements and logistics for third host site (Burger Station).
- Assemble the machined specimen and core pieces for the remaining probes.
- Complete the instrumentation and controls systems for remainingr probes.
- Install blowers and controls at two host utility sites.

- Continue site installation tasks, coordinating with host utilities.

Task 4C Steam Loop Design, Construction, and Testing

Objectives:

The objectives of this sub-task are to design, build, and test two 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 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:

During January, there was no opportunity to repair the leaking pressure tap fitting on the attemperator, which has disabled the attemperators and is limiting operating temperature (inlet valves are open). It was determined that the leak is at a threaded fitting that has also been welded twice. That fitting will be replaced with a welded design and a new piping section with valve will be shop fabricated to eliminate this nuisance problem. It will be installed at the next opportunity, which may be the upcoming outage expected sometime in late March. Although we have been verbally told (by plant personnel) that operation can continue until spring 2006 to make up time at temperature lost due to the fitting leakage problems, it is not in writing from Reliant. Since there is concern that pressing for a letter may have an undesirable outcome, the impact of a request for a letter is being investigated through plant personnel. A meeting was attended in Washington DC to discuss ways to incorporate oxygen combustion issues into the USC Materials program.

During a brief outage in February an attempt was made to repair the leaking pressure tap fitting on the attemperator, which has limited operating temperature (inlet valves are open), and the thermocouple on Section B which was wired wrong. The leak was temporarily re-welded during the outage. The entire section of piping that has been leaking was redesigned and will be replaced during the outage now scheduled to begin April 23 for four weeks. In addition, the thermocouple on Section B was repaired. However, upon restart it was found that the thermocouple on Section A was apparently disturbed during the repairs indicating a short so the inlet valve on Section A remains open. The problem is believed to be in a junction and it will be repaired at the next opportunity or during the upcoming outage. Upon restart, the controller for the control

valve on section B malfunctioned and will need to be replaced. Parts are on site but cannot be replaced until the outage due to the hot environment. During the outage, the system will be thoroughly inspected and tested, to the extent possible, to insure proper operation when the outage is over.

No further opportunities to make any repairs occurred in March and preparations have been made for the outage to begin in late April.

Concerns:

None.

Plans for Next Quarter:

- Replace the piping and valve in the attemperator piping to eliminate the fitting that has leaked.
- Correct loose junction in the Section A thermocouple.
- Replace Section B controller.
- Thoroughly inspect the two sections and the system and test, to the extent possible, to insure proper operation after the outage.
- Continue to monitor operation and collect data.

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:

- As with a gas tungsten arc welding process that used matching filler metal, a process using a gas tungsten arc root and a shielded metal arc fill was developed and qualified for butt joints in the 2-inch OD x 0.400-inch MWT tubes cut from the SAVE 12 piping. Initial attempts had failed bend tests but imposing a relatively long, high temperature post weld heat treatment facilitated qualification.
- The investigation of the SAVE12 thick section (13.78-inch OD x 2.3-inch wall pipe) weld failures was completed with the assistance and cooperation of the ALSTOM Materials Technology Center. The information obtained during this investigation demonstrated that the submerged arc portion of the weld deposit contained

significant amounts of re-formed (i.e., untempered) martensite. The presence of the martensite had reduced the ductility of the weld deposit and resulted in bend and tensile test failures. The presence of substantial quantities of re-formed martensite was traced to the welding flux used for the submerged arc portion of the weld. The initial flux chosen was an agglomerated fluoride flux designed for welding highly alloyed steels. While the flux chemistry was within the specification of both the base material and the weld metal composition in addition to being identified by the manufacturer as a neutral flux, the submerged arc process actively increased alloying of both the nickel and manganese. The amounts of both nickel and manganese were found to be substantially higher in the submerged arc portion of the weld deposit compared to either the gas tungsten arc or the shielded metal arc portions. The greatly increased levels of nickel and manganese had caused a substantial reduction in the lower critical transformation temperature (A_1) of the weld metal so that, at a PWHT temperature of 1450°F, a significant portion of the submerged arc deposit was re-austenitized. Upon cooling from the PWHT temperature, the austenite transformed to fresh martensite thereby compromising the ductility of the deposit

- Two new welding fluxes have been sampled using test beads deposited on pieces of the SAVE12 base material with the submerged arc process. The resultant chemistry of the test beads will be determined for each of the new welding fluxes in order to:
 - Establish a weld metal chemistry closest to the SAVE12 base material in order to confirm there will be no surprises in alloying element concentrations in the welding process.
 - Determine the actual lower critical transformation temperature (A_1) of the weld metal.

Pending the evaluation of the new welding fluxes, the re-qualification of the SAVE12 thick section pipe is planned for April or May of 2005..

Haynes 230:

Test welds were made at Lincoln Electric using their newest pulsed gas metal arc welding techniques. The results were excellent and this process will be used to make thick section weldments for testing by ORNL. Three-inch thick plates have been machined in preparation for the fabrication of these weld specimens.

Inconel 740:

- The Lincoln Electric pulsed gas metal arc welding techniques were also tried at Special Metals on Inconel 740. The results were good but some procedure refinement is needed because a few microfissures still develop in the area of the cap layer.

- Special Metals performed confirmatory tests to show a heat-to-heat difference in sensitivity to microfissuring. Discussions were held relative to chemistry modifications which could help reduce microfissuring (carbon and minor element reductions).

CCA 617:

VDM provided a list of critical parameters that need to be checked when using the matching filler metal but none of these solved the weldability problem. Attempts are being made to have a VDM welding expert meet with the ALSTOM welders in Chattanooga, TN as a direct approach to this issue.

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 might prove insurmountable for this program.
- Inconel 740 appears to have a heat-to-heat sensitivity with regards to microfissuring which could require additional constraints on composition.

Plans for the Next Quarter:

- Continue qualification efforts on SAVE 12 pipe butt weld processes using matching filler metals.
- Determine efforts required to develop a gas metal arc welding process to make butt joints in Super 304H tubing.
- Continue to study problems with shielded metal arc welding of CCA 617 thick plates.
- Continue to study the problems with heat affected zone microfissuring in Inconel 740 when using gas tungsten arc and pulsed gas metal arc welding processes.
- Perform analyses to compare weld metal chemistries for gas tungsten arc and gas metal arc welding on Inconel 740. Some element loss is expected during gas metal arc welding compared to that with the gas tungsten arc process.

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:

Butt joint weld samples using the 2-inch OD x 0.400-inch MWT tubes cut from the SAVE 12 piping, a Grade 92 filler metal, and the gas tungsten arc and gas tungsten arc/shielded metal arc welding processes were fabricated and supplied to ORNL for evaluation.

Concerns:

None.

Plans for the Next Quarter:

- Prepare test samples from SAVE 12 tube and pipe welds using matching filler metals for ORNL evaluation.
- Prepare three-inch thick Haynes 230 test plates using pulsed gas metal arc welding for ORNL.
- Begin fabrication of Inconel 740 test plates using gas tungsten arc welding.

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:

1. No progress to report.
4. No progress to report.
5. Testing to evaluate the susceptibility of Inconel 740 to post weld heat treatment cracking using Gleeble stress-relaxation and high-temperature tensile tests was completed. The behavior of Inconel 740 was compared to that of Inconel 718 and Waspaloy, which are commonly used Ni-based precipitation-hardening alloys, and it was concluded that Inconel 740 is not very susceptible to this type of cracking.
6. Based on low and medium heat input welding conditions used in the field, thermal cycles were determined for low temperature and high temperature regions of a weld heat affected zone. Sample material was annealed and aged in preparation for the simulation heat treatments, specimens were machined, and the simulations, using a Gleeble machine, were completed. The specimens are now ready for the mechanical property testing.

Concerns:

None.

Plans for the Next Quarter:

- Evaluate mechanical properties of Gleeble-simulated heat affected zones in Inconel 740.
- Start mechanical characterization of full-size welded joint that will be provided by B&W.

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:

Gas tungsten arc and shielded metal arc processes for making dissimilar metal weld butt joints between HR6W and Save 12 tubing were qualified. The gas tungsten arc process used Inconel 82 filler whereas Inco-Weld A was used for the shielded metal arc process.

Concerns:

None.

Plans for the Next Quarter:

- Complete CCA 617/Super 304H test samples.
- Fabricate samples of dissimilar metal joints between the HR6W and SAVE12 tubing.

Task 5: Welding Development - Milestone Chart
(DOE Fiscal Year Basis)
(percentages indicate fraction of workscope completed as of 2005Q2)

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.				△			85%									▲				
	• Preliminary weld trials and parameter optimization – thick section.				△			85%									▲				
5C	Preparation of Laboratory Samples																				
	• Material preparation.							△	80%								▲				
	• Sample fabrication.							△	80%								▲				
5D	Weldability Testing												△	60%			▲				
5E	Examination of Dissimilar Metal Welds.																				
	• Weld trials											△	35%				▲				
	• Metallurgical analysis											△	0%				▲				
	• Analysis and test case.											△	0%				▲				

Accomplishments Versus Expenditures (Alstom)

The main reason for the deviation between expenditures and accomplishments was the higher than expected costs for the nickel base materials that had to be purchased for the program.

Task 6 Fabrication (B & W)

Objectives:

The objective of Task 6 is to establish boiler fabrication guidelines for the high temperature, 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.

- Samples of the 2" OD HR6W and SAVE12 have been bored out to a wall thickness 0.200".
- Base material properties and variability are being measured and evaluated for the SAVE12 and HR6W. Although most of the welding and fabrication trials have already been completed, a particular interest is in the degree of property variation or stratification in the pipe and tube shapes, especially the SAVE12 tubes manufactured from pipe.
- Complete sets of the SAVE12 and HR6W 2.0" x 0.40" bends without heat treatment have previously been sent to ORNL for testing. After the recrystallization study results are available, Riley will determine the appropriate heat treatments applicable to these materials and additional samples of the materials will be sent to ORNL for testing.

Concerns:

None.

Plans for the Next Quarter:

- During the next quarter, Riley plans to begin the preparation of summary reports on the history and accomplishments of the material fabricability efforts.
- Swaging of the tubes from 2.0" down to 1 ¾" OD and from 1 ¾" OD down to 1 ½" OD will be performed during the next quarter.

- Pending review of the project budget, Riley 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.

- Budgetary concerns and other commitments precluded any activity this quarter by Alstom on Task 6.

Concerns:

None.

Plans for the Next Quarter:

Alstom plans considerably more activity next quarter by completing the tapered tube studies and by supplying the tube bends to ORNL for testing.

Progress for the Quarter: Foster Wheeler

Fabrication of 740:

Bent tubing at Riley Power's Erie Shop. A total of 12 bends were made; four each at the following bend radii: 3-in. (1.5D), 5-in. (2.5D), and 6.75-in. (3.375D). These radii provide outer fiber strains of 33.3, 20, and 14.8 percent, respectively. The following images show a 3-in. radius bend (1.5D) in the In 740 tubing being produced.

FOSTER WHEELER

Because the 740 tubes exhibited a hardness variation around the circumference, it was decided that: in two of the bends of each radius, the hard zone would be situated at the neutral axis; in one bend of each radius, the hard zone would be positioned at the extrados; and in one bend of each radius, the hard zone would be located at the

intrados. In all cases, the bends were made without any problems. The In-740 U-bends that were produced are shown in the following image.

Digital image showing cold bends of IN740 tubing made to bend radii of 6.75R (3.375D), 5R (2.5D), and 3R (1.5D)

Recrystallization Study:

- The following thermal exposures were performed or initiated: **230 Material** - 1650°F for 40.5 hours and 1600°F for 1000 hours; **740 Material** - 1600°F for 100 hours and 1600°F for 1000 hours; and **HR6W Material** - 1600°F for 100 hours and 1600°F for 1000 hours. At the end of the quarter, 900 hours of the 1000 hour exposures have been completed.
- For the exposures that were completed, samples were mounted for metallurgical evaluation. The evaluation is still in progress. Some preliminary highlights are displayed in the images that follow. Extensive recrystallization was noted in the HR6W material at the 48 percent OFS location after 100 hours at 1600°F (first

page); at 13 percent OFS recrystallization was noted to some degree (second page). Insofar as the In740 material, a precipitated phase was evident in the microstructure (third page).

FOSTER WHEELER

HR6W Material – 48 Percent OFS
TOP: As-Strained
BOTTOM: 1600°F – 100 hours

HR6W Material – 13 Percent OFS
TOP: As-Strained
BOTTOM: 1600°F – 100 hours

IN-740 Material – 42.5 Percent OFS
TOP: As-Strained
BOTTOM: 1600°F – 100 hours

Concerns:

None.

Plans for the Next Quarter:

Plans for next quarter are to perform a dimensional analysis and hardness survey on the bends. A complete set will also be sent to ORNL for testing.

Plans for next quarter are to continue evaluation of the 100 hour exposure, complete and evaluate the 1000 hour exposures, and perform additional exposures as necessary.

Progress for the Quarter: B&W

Task 6 project activities have been on hold since January 1, 2005 pending authorization and release of funding for GFY 2005.

Concerns:

None.

Plans for the Next Quarter:

Microstructures of alloy 230 bends (extrados, neutral axis, and intrados) will be examined, characterized, and compared to microstructures produced in the controlled strain/recrystallization/precipitation studies.

Swaging trials with Alloy 230 tubes machined to 2" OD X 0.200MW are planned.

Construction of an Alloy 230 (fabrication) demonstration article will begin.

TABLE 6
Schedule and Progress

ID	Task Name	Start	Finish	Status	2000				2001				2002				2003				2004				2005				2006	
					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	Q2
1	Task 6: Fabricability	Tue 1/1/02	Thu 3/31/05	In Progress																										
2	6A: Fab Trials for SH	Tue 1/1/02	Mon 8/8/05	In Progress																										
3	6A.1 SH Trial	Tue 1/1/02	Mon 8/8/05	In Progress																										
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 8/8/05	In Progress																										
7	Cold Bending Trials	Mon 6/2/03	Mon 8/8/05	In Progress																										
8	Cold Swaging Trials	Mon 6/2/03	Mon 8/8/05	In Progress																										
9	Butt Welding Trials	Mon 6/2/03	Fri 6/4/04	Complete																										
10	Attachment Welding Trials	Mon 6/2/03	Fri 6/6/04	Complete																										
11	6A.2 Reporting	Fri 1/3/03	Mon 8/8/05	In Progress																										
12	6A.3 SH: Met Test & Eval	Fri 1/9/04	Mon 8/8/05	In Progress																										
13	6A.3.1 Mic Bends&Welds	Fri 6/4/04	Mon 8/8/05	In Progress																										
14	6A.3.2 HT Studies&Mic	Fri 6/4/04	Mon 8/8/05	In Progress																										
15	6B: Fab Thk Wall Comp	Fri 1/9/04	Thu 10/6/05	In Progress																										
16	6B.1 Thick-Wall Fab Trial	Fri 1/9/04	Fri 6/3/05	In Progress																										
17	6B.2 Reporting	Fri 1/9/04	Thu 10/6/05	In Progress																										
18	6B.3 Thick-Wall Comp	Fri 1/9/04	Fri 6/3/05	In Progress																										
19	6B.3.1 Met Analysis	Mon 6/6/05	Thu 10/6/05	Planned																										
20	6B.3.2 PWHT Studies&Mic	Wed 9/29/04	Thu 10/6/05	In Progress																										

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 7F: Process Optimization

Objective:

Perform coating process optimization at an intermediate scale between laboratory and commercial size.

Progress for the Quarter:

Part 1: B&W Effort

None.

Part 2: Alstom Effort

Test run #6 was completed and specimens analyzed. This is the last test run planned. Overall conclusions are the following:

1. ID diffusion layers of adequate thickness and composition can be achieved provided that the tubing pieces are end-capped.
2. OD pack powder is not a necessary condition for the growth of consistent ID diffusion layers.

Concerns:

None.

Activities Planned for Next Quarter:

No work planned. Initiate Task 7G with the objective of issuing ID manufacturing guidelines.

Task 7H: Specimens for Field Corrosion/Oxidation

Objective:

Provide externally and internally coated specimens for inclusion in corrosion/oxidation testing under Tasks 3 and 4.

Progress for the Quarter:

No work performed in the reporting period.

Concerns:

None.

Plans for the Next Quarter:

Task has supplied specimens as needed; additional activity dependent on need for additional specimens.

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
Task 7: Coatings																					
Task 7A: Detailed Study of Current State of the Art																					
Altom Task 7A: Detailed Study of Current State of the Art	Complete																				
Task 7B: Coating Feasibility (Internal Coating)																					
Altom Task 7B: Coating Feasibility (Internal Coating)	Complete																				
Task 7C: Coating Recommendations																					
Altom Task 7C: Coating Recommendations	20%																				
Task 7D: Laboratory Testing																					
Altom Task 7D: Laboratory Testing	60%																				
Task 7E: Process Scale Up - Preliminary Trials																					
Altom Task 7E: Process Scale Up - Preliminary Trials	Complete																				
B&W Task 7E: Process Scale Up - Preliminary Trials	87%																				
Task 7F: Process Optimization																					
Altom Task 7F: Process Optimization	Complete																				
B&W Task 7F: Process Optimization	87%																				
Task 7G: Manufacturing Recommendations																					
Altom Task 7G: Manufacturing Recommendations																					
B&W Task 7G: Manufacturing Recommendations	30%																				
Task 7H: Specimens for Field Corrosion/Oxidation																					
Altom Task 7H: Specimens for Field Corrosion/Oxidation	Complete																				
B&W Task 7H: Specimens for Field Corrosion/Oxidation	55%																				
Task 7I: Project Management																					
Altom 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:

Activities on Task 8 were minimal due to delayed funding release from DOE/EIO.

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 creep rupture test results for the HR6W material, assigned to Riley. Very recently, additional results have been posted on the website. They consist of seven more completed creep rupture test results for HR6W, together with chemistry results, and three creep rupture test results for HR6W tubes with Grade 617 and/or 82/182 welds. For SAVE 12, the other material assigned to Riley, there is a table presented of chemical compositions of the base metal and filler metals.

Due to funding limitations, the other participants did not perform any work on this subtask.

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. 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:

As reported last quarter, funding issues for both ALSTOM and B&W hampered progress. Also it is only very recently that additional test data has been uploaded to the ORNL data transfer web site. The structural feature (e.g. notched bar) tests (Task 2) continue and will ultimately provide useful data for this subtask, but since such testing requires long duration it is unlikely that significant progress will be made on this subtask in the next quarter.

Concerns:

Timely availability of creep data on ORNL web site and results of notched bar creep rupture tests. Availability of funds to support Task 8 activities at B&W and ALSTOM also remains a concern.

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.

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:

During this quarter, Riley Power Inc. submitted a revised draft version of the weld literature review summary report to the subtask leader at ALSTOM, for review and comments. Based on previous preliminary review comments, Riley has added a detailed summary section with tables and conclusions to the report. Riley also added the review of an additional paper on the subject of weld strength reduction factors, by Carl Jaske; and cross-referenced two other papers from other sections of the report, which address in part the same subject

Concerns:

None.

Plans for the Next Quarter

Riley Power Inc. will add review summaries of five or six applicable, pertinent papers on welds, which were presented at the October 2004, EPRI, 4th International Conference on Advances in Materials Technology for Fossil Power Plants. This would be contingent upon available time and funding. Based upon the current level of involvement, it does not seem possible at this time to add a section on dissimilar welds, since there are so many applicable papers on this subject. This topic could be included in a possible future separate report. Finally, Riley plans on meeting with the subtask leader for a final review, and also assisting with the issuance of the completed summary report on the weld literature review.

ALSTOM plans to review the draft report prepared by Riley Power Inc. and work to expand / add sections dealing with weld analysis and design methods. It is likely that a number of simple analyses to evaluate various methods will be performed to support this effort.

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:

Proposed amendments to Section 1 of the Code was accepted and the reference stress based formula will appear in a future revision of the Code.

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 Task:

- Completed First Quarterly Report for 2005.
- Completed Monthly Reports for January and February, 2004.
- Monthly conference calls were held and the discussions were documented.
- Conducted meeting on Oxygen Firing in Washington on Feb. 14, 2005.

Concerns:

None.

Plans for the Next Quarter:

- Issue monthly reports and hold conference calls as required.