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INTERIM STATUS REPORT

January 22, 1964

to

U.S. Atomic Energy Commission
Chicago Operations Office
Lemont, Illinois

MASTER

SODIUM-HEATED STEAM GENERATOR
DEVELOPMENT

AEC CONTRACT NO. AT (11-1) - 1280
B&W CONTRACT NO. 610 - 0067

THE BABCOCK & WILCOX CO.
BOILER DIVISION

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DEVELOPMENT

Signed: _____

Paul Perbet

THE BABCOCK & WILCOX CO.
BOILER DIVISION
BARBERTON, OHIO

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ABSTRACT

This Report is an Interim Status Report on this Contract. The information contained herein was prepared for presentation to the Sodium Components Development Program Information Meeting, August 21, 1963, at Palo Alto, California. Some of the slides prepared for that meeting were in color which would not reproduce for this report, so similar black-and-white sketches are substituted here and the text has been modified accordingly.

Objective:

The Objective of our steam generator design Contract is to develop an economical, practical, reliable large central station sodium heated steam generator.

Scope of Work:

The Scope of Work under this Contract is divided into two phases as follows:

Phase I:

- A. Preliminary Design of Full Size Steam Generator.
(By Full Size is meant 1000 MWE in three units).
- B. Supporting Research and Development Work.
- C. Preliminary Design of 30 MWT Prototype Steam Generator.

Phase II:

- A. Detail Design of 30 MWT Prototype Steam Generator.
- B. Fabrication of 30 MWT Prototype Steam Generator and delivery to the SCTI at Santa Susana, California. The testing will be done by AI.
- C. Final Report relating the performance of the 30 MWT Prototype to the design of the Full Size Steam Generator.

Changes in Scope:

There have been two changes in Scope from the original Contract.

1. In the original design it was proposed to handle a heat load of 1000 MWT. For reliability reasons this thermal capacity was divided among three steam generators having 333 MWT each. After design work was begun on these steam generators it was learned that the 1000 MWT represented only one loop of a three loop plant. If each loop had three steam generators that would make a total of nine steam generators for the total plant and would add to the cost, but would add very little to the reliability of the overall plant. The scope of work under the Contract was modified to describe a steam generator of a size such that three identical steam generators would produce enough steam for 1000 MWE.

2. Another change in scope was negotiated to raise the steam pressure from the 2200 psi as specified in the original inquiry to 2400 psi at the turbine. This change will bring the steam pressure into agreement with the "preferred standard" steam turbine design conditions common in the industry and will result in a cost saving in the steam turbine. This change will not effect the size or cost of the steam generator.

Under this Contract there are six research and development projects.

These projects are as follows:

1. Materials - carbon transfer and effect on material properties
2. Effect on heat transfer and two-phase flow of coiling tubes
3. Corrosion of Croloy 2 1/4 in products of sodium-water reaction
4. Procedure for welding tube to back side of tube sheet
5. Radiographic inspection of back side tube welds
6. Chemical simulation of sodium environment for leak testing

The status of each of these R&D projects will be discussed later.

Description of Sodium and Steam Cycle Conditions:

Figure 1 is a pictorial schematic diagram of one secondary sodium loop from the Full Size Plant. The Intermediate Heat Exchanger shown on this diagram is not part of our Contract. This diagram shows both a steam generator and a reheater. An evaluation was made, and the fuel cost saving resulting from the higher cycle efficiency using a reheater more than offset the additional cost of the reheater. It is not planned to operate a Prototype of the reheater at SCTI because the problems in the reheater will be similar to those in the steam generator, and the steam generator problems will probably be more severe because of the higher steam pressure.

Sodium flows downward through the steam generator and reheater in parallel, and these flows join and go back to the Intermediate Heat Exchanger. The water comes from the feedwater pump and flows upward through the steam generator where it changes to steam at 2400 psi 1050 F and goes

to the steam turbine. From the high pressure section of the steam turbine the steam flows back to the reheater where it is heated again to 1000 F and flows back to the low pressure stages of the steam turbine. Separate control valves in the sodium lines control the steam temperature leaving the steam generator and reheater.

Figure 2 is a plot of cycle efficiency versus load for a 2400 psi 1050 F plant with reheat to 1000 F. You will observe that the efficiency at Full Load is 43 per cent. This compares to an efficiency for a pressurized water reactor plant of approximately 33 per cent. There is a significant gain in efficiency by going to high pressure and temperature. Fuel costs are low for a nuclear plant, but even so they are significant in large plants, and the saving in fuel cost because of higher efficiency is well worth shooting for.

Figure 3 is a plot of feedwater temperature, steam temperature leaving the steam generator, and reheat steam temperature to and from the reheater. The significant thing shown here is that by controlling the flow of sodium to the steam generator and reheater it is possible to keep the main steam and reheat temperatures constant from full load down to 20 per cent load.

Figure 4 is a plot of sodium flow through the steam generator, reheater, and by-pass line. By proper adjustment of these flows as shown it is possible to maintain the constant superheat and reheat temperature characteristic shown on Figure 3. At full load no sodium is by-passed around the steam generator. As load is decreased the amount of by-pass will increase to a maximum of approximately 3.0×10^6 lb/hr. then decrease to 2.4×10^6 lb/hr.

Figure 5 is a plot of sodium temperatures from the Design Specifications. The average sodium temperature in the steam generator is almost constant at all loads. Inlet and outlet sodium temperatures diverge as load increases. This infers that to satisfy these conditions the reactor will operate with

an increasing reactor average temperature with increasing load. This may be a problem for the reactor designer -- to operate with an increasing reactor average temperature.

STEAM GENERATOR LOOP

FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

GENERAL DESCRIPTION OF DESIGN:

To meet the overall Commission objective of developing economical, practical nuclear power, the steam generator being designed under this Contract will be of the "once-through" type because economic studies have shown that the once-through boiler costs considerably less than a recirculating boiler, especially in large sizes.

A single tube wall will be used because it is felt that adequate safety measures can be provided to protect personnel and to protect the boiler against severe damage in the event of a tube rupture, and by using a single tube wall a considerable saving in cost results.

A very compact arrangement of heating surface is possible by using concentric helical coils for both the boiler and the superheater. Any sodium-heated boiler will be subjected to rapid sodium temperature changes. The tube sheets are the thickest metal sections in the boiler and, therefore, most sensitive to temperature transients. To protect the tube sheets against these rapid sodium temperature transients they are located up in the gas space, out of the sodium.

The boiler bank will be made of a low cost alloy such as Croloy 2 1/4 because the tube temperatures are within the use limits for this material. For the high temperature superheater, a material must be used having good stress characteristics at high temperature. Type 316 Stainless Steel and several other alloys are being investigated for possible application in the superheater.

To protect the shell against sodium temperature transients and also against corrosion in the event of a sodium-water reaction there is a steel liner within the main pressure shell extending above the sodium

level at the top and sealed to the sodium outlet nozzle. The annular space between the liner and the main shell is filled with argon gas. This will provide insulation against thermal transients and will act as a cushion to protect the shell against pressure surges resulting from a sodium-water reaction.

FULL SIZE STEAM GENERATOR: (1000 MWe in 3 Units)

By referring to SK 520 one can trace the flow paths of sodium and water through the steam generator. The sodium enters through two 24-inch sodium inlet nozzles at the top of the steam generator and flows downward through a distributor system which will assure uniform flow across the tubes at the entrance to the superheater and will prevent local high velocity streams from causing vibration difficulties in the superheater. The sodium flows downward in cross flow across the helical coil superheater and continues down across the helical coil boiler bundle where it changes to steam and passes upward through the riser tubes to the four boiler outlet nozzles. The steam flows through interconnecting piping to the four superheater inlet connections, flows downward through the superheater inlet tubes in the annular space around the superheater, then turns and flows upward through the coil superheater and out through the four superheater outlet nozzles.

Since the boiler is made of Croloy 2 1/4 and the superheater is made of Type 316 Stainless Steel there must be a dissimilar weld in the piping. The boiler is arranged so that the dissimilar weld in the steam piping will be located outside the boiler so that the dissimilar weld can be inspected easily and so that if a leak should occur it will be a leak from the steam to the atmosphere rather than a leak resulting in a sodium-water reaction.

LAYOUT OF SODIUM STEAM GENERATOR

S PERGINSKIE 9-12-63

SK- 520

REHEATER:

The reheater will be located in a separate vessel situated as close as possible to the steam turbine to save reheat steam piping and pressure drop. Because of the comparatively high specific volume of the reheat steam, the steam piping is large and expensive. It will be less expensive to pump the sodium to the reheater located near the turbine then to take the steam from the turbine a long distance to the reheater.

The first concept of the reheater is a helical coil to bundle suspended from a flat cover having integral tube sheets and steam headers. Preliminary stress calculations show that the flat tube sheets will be satisfactory for the 625 psi design pressure of the reheater although they would not be satisfactory for the higher pressure existing in the boiler. Calculations of steady state thermal stresses in this reheater cover and tube sheets are proceeding.

RESEARCH AND DEVELOPMENT PROGRAM:

MATERIALS - carbon transfer and effect on material properties

Background Information

There are actually two problems relating to materials and their application for a sodium-heated steam generator.

There is the problem of carbon and mass transfer on the sodium side of a tube, and also the problem of possible accelerated corrosion at the location of Departure from Nucleate Boiling on the steam side of the tubes.

It is well known that materials used in sodium systems above 900 F undergo mass transfer whereby materials are dissolved from the tube walls in the hot zone and deposited in the cooler zone. In addition to this, there is a tendency for ferritic materials such as Croloy 2 1/4 to decarburize in sodium and for the carbon to deposit out on austenitic stainless steel surfaces in the same sodium circuit. Considerable work has been done on mass transfer and carburization-decarburization problems, but it is evident that further work is required to determine if these problems will be of concern in a closed loop with the relative qualities of Croloy 2 1/4 and Type 316 Stainless Steel involved in this design.

Tests have shown that accelerated corrosion can occur in boiler tubes at the location of DNB under certain conditions. Under some conditions a boiler tube can fail by corrosion at the DNB point in less than 24 hours.

This corrosion is controlled in fossil fuel fired boilers by careful control of water chemistry and by designing

the boiler to have the DNB point occur in a zone of low heat flux. The relatively low heat flux at the DNB point comes about because of the necessity of protecting the tube from overheating ("burnout") when nucleate breaks down and film boiling sets in.

In this sodium-heated boiler there are no extremely high temperatures such as found on the gas side of a fossil fuel fired boiler, but because sodium is so much better a heat transfer medium than gas there can be very high heat fluxes with moderate temperature differences between sodium and water.

Tests which have been conducted on model once-through sodium-heated steam generators at temperature levels below those for which this boiler is being designed showed a small amount of corrosion had taken place. It is felt that further experimentation is required at the temperature levels of interest for this steam generator to be able to say with assurance that serious corrosion will not occur.

Objective:

The purpose of this program is to study the carbon and mass transfer effects in a sodium-heated steam generator containing both austenitic and ferritic materials, and to determine that these materials will be satisfactory on both the sodium and the water side for use under the planned operating conditions.

Scope:

A schematic diagram of the test apparatus is shown on

Figure 1. The test boiler will consist of a one-tube model steam generator having a Croloy 2 1/4 boiler section and a Type 316 Stainless Steel superheater section. The proportion of Croloy 2 1/4 and Stainless Steel will be arranged to simulate the proportions of these materials in the Full-Size Steam Generator, and the ratio of surfaces exposed to volume of sodium will be made to duplicate the full-size boiler as closely as possible. Sodium will be circulated outside the tube in the model boiler at flow rates and temperatures simulating the full-load boiler, and steam will be generated within the tube at pressures and temperatures similar to the full-load boiler. The sodium system consists of an electromagnetic pump, flow meter, sodium heater, plugging indicator, cold trap, and pump. The water-side system includes a reservoir, pump, heater, boiler and superheater, condenser-cooler section, and a back pressure regulator.

In operation, water will be circulated from the reservoir by a recirculating pump into the boiler section at a pressure of 2450 psi and 600 F. Steam will leave the superheater at 2400 psi and 1050 F. The superheated steam is passed through a condensing cooler section, through a back pressure regulator to control the system operating pressure, and back into the reservoir for recirculation.

The sodium system will include the necessary accessory components to provide the required operating conditions and to maintain any sodium purity.

The test operation will continue for approximately one

SODIUM HEATED BOILER TEST LOOP

FIGURE 1

year during which the unit will be subjected to steady-state conditions as well as transient operation. In this way, the full range of anticipated service will be duplicated. Samples will be removed and examined during the test operation to get preliminary test results. Following the test, the unit will be disassembled and the materials examined by appropriate techniques such as metallographic, electron microprobe, electron microscope, and spectrographic means.

Program Schedule:

The following tables shows the estimated schedule for the program described above:

<u>Program Schedule:</u>	<u>No. of Weeks</u>
Design & Construction	16
Testing	52
Analysis & Report	<u>6</u>
Total	74

EFFECT ON HEAT TRANSFER AND TWO-PHASE FLOW OF COILING TUBES

Background Information

In any once-through boiler, water enters subcooled and leaves as superheated steam; so somewhere in the boiler nucleate boiling will break down and film boiling set in. The heat transfer conductance under film boiling conditions is much lower than under nucleate boiling so that with a constant sodium temperature outside the tube, the tube wall temperature will increase sharply when film boiling begins. The DNB fluctuates up and down the tube so that a point on the tube wall will see a cycling boiling conductance and a cycling inner wall temperature. This resulting cycling thermal stress is of concern since it may cause fatigue failures of the tube wall.

In addition to the thermal stress consideration, the amount of heat transfer surface area required for a boiler will be in error if predictions of the location of DNB and film boiling conductance are in error.

A great amount of work has been done over the past 15 years by the B&W Company and others on film boiling problems, but all of the prior work has been done on straight tubes. The boiler being designed under this Contract has helical coil tubes to make optimum use of the space available in the cylindrical steam generator vessel.

Objective

The purpose of this program is to determine the effect of making a tube in a coil configuration on:

- 1) the location of the Departure from Nucleate Boiling,
- 2) the nucleate and film boiling heat transfer conductances.

The results of this program are essential to be able to determine accurately the amount of heat transfer surface required for the steam generator being designed under this Contract and to be assured the tubes will not suffer fatigue or corrosion failures due to temperature fluctuations at the DNB point.

Scope

In this R&D Program we are fortunate that the test facility is already in existence at B&W's Alliance Research Center. This facility has been in use for a number of years investigating boiling problems, and the operation of the facility and technique for obtaining reliable data have already been proven out.

A schematic diagram of the test facility is shown on Figure 2. It will be noted that there are two separate water loops in this test facility. Each has pumps, flow measuring devices, and a flow control valve. One loop flows through the once-through boiler to the mixing tee. By adjusting the flow in this loop and the heat input to the gas fired once-through boiler it is possible to obtain steam at various enthalpies entering the mixing tee. The other water loop is unheated and flows directly to the mixing tee. By mixing the flow from these two loops it is possible to adjust the enthalpy of the mixture entering the electrically heated test section over a wide range. This allows independent control of the location of the DNB point in the test section, and the heat input. The versatility of this test facility has proven to be of great value in the study of the DNB problems and film boiling. The steam leaving the electrically heated test section passes through throttle valve then is condensed and recirculated through the test facility. A demineralizer and deaerator are installed to maintain the purity of the water in the facility.

For this program, a curved test section will be fabricated and installed in this test facility. This test section will be operated

SCHEMATIC OF HIGH PRESSURE BOILING WATER
HEAT TRANSFER APPARATUS

FIGURE 2

over a range of heat fluxes and water velocities simulating the operating conditions of the full-size boiler. The test section will be instrumented with thermocouples, voltage taps. The location of the point of DNB will be determined, and the affect on tube temperature recorded. These data will be compared with similar data for straight tubes to determine the effect on boiler design.

Program Schedule

The following table shows the estimated schedule for the proposed program:

<u>Program Schedule</u>	<u>No. of Weeks</u>
Design & Construction	16
Testing	20
Analysis & Report	<u>16</u>
Total	52

CORROSION RATES FOR CROLOY 2 1/4 STEEL IN PRODUCTS OF A SODIUM-WATER REACTION

Background Information

Tube failures, due to sodium-water reactions, can result from stress corrosion cracking, apparent metal fatigue, and bulk transcrystalline corrosion. Considerable interest has been generated in this latter type of metal failure, and little is known of its rates under the widely varying environmental conditions which can exist.

Examples of such corrosion can be found in the tube failures at Enrico Fermi Power Plant. In one area where a sodium-water reaction occurred, blisters with longitudinal cracks were noted. The wall thickness of the tube at the point of the reaction was reduced by about 1/2.

With such effects on tubes in a steam generator during a sodium-water reaction, it is necessary to know as much as possible about this corrosion caused by the products of reaction. This knowledge affects two areas of sodium-heated steam generator design — operation and materials selection.

During normal operation, hot sodium is circulated through the steam generator. If a sodium-water reaction occurs with its associated products of reaction, the station operator has two choices in regard to sodium flow, (1) shut off the sodium flow to the steam generator and permit sodium temperature to decay to the isothermal condition, or (2) keep the sodium flowing and maintain a specific temperature in the unit. Since the products and rates of reaction are temperature dependent, it may be advantageous to maintain a predetermined sodium temperature to lessen the corrosion effects of a sodium-water reaction.

The program described below is directed toward the assembly of the necessary test equipment, and the determination of corrosion rates for Croloy 2 1/4 steel in hot aqueous solutions of sodium hydroxide, and in suitably equilibrated solutions of sodium hydroxide in molten sodium. Corrosion rates in pure sodium will be determined in order to establish base values for this work.

Croloy 2 1/4 steel is used for this project since it is more susceptible to gross corrosion in a sodium environment than any of the stainless steels to be used for other parts of the system. Although the austenitic steels are more susceptible to stress corrosion, extensive work has already been done in this area by B&W and others. This data is available for use in the Sodium-Heated Steam Generator Development Program.

Objective

The objective of this program is to provide information pertaining to the rate of corrosion of Croloy 2 1/4 steel with reaction products of water-to-sodium leak. A second objective is to be able to postulate the mechanism of reaction between Croloy 2 1/4 steel and the sodium-water reaction products. With such information, it will be possible to determine if there are operational procedures which will reduce the corrosion effect of a sodium-water reaction on the tube material. Also, the tests will indicate what products of corrosion will affect the tube material and to what extent.

Scope

In a sodium-water reaction, the resulting products are sodium hydroxide, sodium monoxide, and at a temperature less than 800 F — sodium hydride. The most corrosive compound resulting

from this reaction is sodium hydroxide (aqueous). The rates of corrosion of Croloy 2 1/4 steel in hot aqueous solutions of sodium hydroxide will be determined. Corrosion products caused by the reaction can exist in almost any concentration. Therefore, the concentrations of sodium hydroxide will be varied from approximately 25 to 98 per cent, and corrosion tests will be made at five different temperatures for each concentration. Corrosion tests in these solutions will be made to temperatures as high as their boiling points at atmospheric pressure.

The corrosion testing of sodium hydroxide in sodium will be conducted on Croloy 2 1/4 at the saturation level at five temperatures varying from 400 to 1500 F. These tests will be made under a dry inert atmosphere. The solution will be stirred to renew the solid-to-liquid innerface. Other tests will be performed with a partial pressure of hydrogen over the sodium-sodium hydroxide solutions to simulate the presence of sodium hydride in the solutions.

In order to have a basis for comparison of tests, Croloy 2 1/4 specimens will be subjected to pure molten sodium at the same temperature as those used in the test.

Metallographic examinations of the specimens will be performed to ascertain any change which may occur in the grain structure of the metal, as well as the form of metallurgical damage. These specimens will be weighed before and after the corrosion tests are conducted to determine the loss of weight during the test period.

The experimental work outlined above will do two things. First, it will establish the effect of sodium hydroxide on Croloy 2 1/4 steel as a function of concentration and temperature of the sodium in a steam generator. Since the bulk temperature of the sodium in steam generator can be controlled, operating procedures can be written to minimize the temperature effects of corrosion resulting from a sodium-water reaction.

Second, the amount and nature of corrosion can be determined. With this information, the extent of damage to a boiler tube bundle caused by sodium-water reaction can be estimated, and tube bundle life can be predicted.

Program Schedule:

The time to complete this project will be approximately 56 weeks.

PROCEDURE FOR WELDING TUBES TO BACK SIDE OF TUBE SHEET

Background Information

An expanded and seal welded tube-to-tube sheet joint can develop a crevice exposed to the sodium side. Sodium vapor will collect in this crevice. When the steam generator is shut down for maintenance, moisture laden air finding its way into the sodium side of the unit will result in the formation of a strong caustic solution concentrated in the crevice thus presenting the classical conditions for stress corrosion of stainless steel or "caustic embrittlement" of ferritic alloys.

One way to eliminate the above problem is to machine a projection on the sodium face of the tube sheet at each tube and butt weld the tube to this projection.

The Company has a machine under development for making inexpensive tube-to-tube sheet butt welds. The development of this welding machine, welding processes, and the quality control procedures will be completed to demonstrate a commercially feasible process for making the tube-to-tube sheet welds on the subject steam generator.

Scope

The development work under this program is to complete the development of the welding machine and quality control procedures and demonstrate the ability to produce sound welds in tubes of the sizes and materials used in the boiler being designed under this Contract.

For use with this welding machine, the tube sheets will be machined with projections or lips around each tube hole on the sodium face. A rod with an expanding grip will reach through the tube hole in the tube sheet into the end of the tube. An air cylinder will exert a pull on the rod to draw the end of the tube lightly against the projection on the

tube sheet. A carefully controlled current will be passed through the rod and grip to the tube through the lip to the tube sheet and to ground. The resistance where the tube is held against the tube sheet will cause heating at this location and the air cylinder will force the tube against the lip and produce a weld. (This general procedure has been used in making tube-to-tube welds in the B&W shops for a number of years.)

Program Schedule:

It is estimated that this program will be completed in approximately 12 months.

RADIOGRAPHIC INSPECTION OF TUBE-TO-TUBE SHEET WELD

Background Information

By welding the tube to the back side of the tube sheet, it becomes possible to x-ray the weld to prove its integrity whereas an expanded and seal-welded tube-to-tube sheet joint cannot be x-rayed.

The best way to radiograph these welds is to wrap the film around each tube and put a source within the tube to radiograph the whole weld at one shot. The alternate method is to take at least two angle shots from outside the tube. A conventional gamma ray source inserted inside the tube gives off its rays from too large a volume to give good definition in the picture. What is needed is a point source of x-rays located within the tube.

Scope

This program is to demonstrate the feasibility of constructing a point source for radiographing the tube-to-tube sheet welds.

If a small ($1/16$ " diameter) sphere of some heavy element is bombarded with electrons, x-rays will be produced emanating from this $1/16$ " point. The source of electrons can be a Beta emitter such as Promethium 147. The heavy element target may be surrounded by the Promethium 147 to produce a composite source yielding x-rays from a $1/16$ " diameter point and the whole source will fit within a steam generator tube. Contacts have been made with companies who manufacture radioactive sources and they feel it should be feasible to make such a source.

Program Schedule

The whole program of demonstrating the feasibility of producing a point source of x-rays and of building a Prototype source will take approximately 6 months.

CHEMICAL SIMULATION OF SODIUM ENVIRONMENT FOR LEAK TESTING

Leaching out of minute slag or oxide inclusions by sodium is well known. Even though metal components are tested by ultrasonics and magnetic particle methods and found to be metallurgically sound, oxide inclusions may still be present. When hot sodium comes in contact with these oxide inclusions, the oxide leaches out leaving areas that are subjected to accelerated attack and ultimate failure.

In a previous sodium-heated boiler proposal, the Company considered shop tests whereby the boiler would be immersed in sodium at operating temperature for approximately three days to leach out any inclusions. The boiler would then be subjected to a mass spectrometer test and any leaks repaired before shipment. However, the many problems associated with handling sodium in a manufacturing facility, together with the problems of cleaning the sodium from the boiler after the test to prevent the absorption of water from the air and possible setting up of stress corrosion, makes this test undesirable.

Recent studies have indicated that it may be possible to find a solution that will react in the same manner as sodium in leaching out oxide but will be easier to handle in a manufacturing facility.

The program to find a suitable reagent to leach out oxide inclusions in Croloy 2 1/4 and Type 316 Stainless Steel will proceed in the following two phases:

Phase I - Feasibility of various reagents for removing oxides:

The two reagents that appear attractive at this time are EDTA (Ethylene Diamine Tetracetic Acid. It is planned to do rough-screening testing of the ability of these reagents to remove oxides from Croloy 2 1/4 and stainless steel material.

Weld deposits on Croloy 2 1/4 and Type 316 Stainless Steel flat plate will be made under inert atmosphere. No fluxing material will be used. The weld beads will consist of oxides of elements present in the flat plate material. In addition to these, beads of molten slag will be deposited on flat plate specimens. Several different fluxes will be used to produce slags of different characteristics.

The ease of removal of the oxides in the beads by either EDTA or Sulfamic Acid will be determined. EDTA is more effective at higher temperatures, so the tests will be conducted at temperatures approaching the breakdown temperature of EDTA (approximately 350 F). Semi-quantitative evaluation will be made by visual and low-power magnification (10x) study of the test specimens after treating with the solutions.

Phase II

If either of these two reagents appear feasible for this application, test specimens can be made up with known oxide inclusions and more exacting techniques used in evaluating the effectiveness of these solutions.