✓
ENGINEERING

CENC 1197

VOLUME I

**LMFBR
SODIUM HEATED
STEAM GENERATOR
—TEST MODEL—**

AEC CONTRACT AT(11-1)-3031

FEBRUARY 1973

MASTER

CE COMBUSTION DIVISION

COMBUSTION ENGINEERING, INC.

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GPO 1971 O 445 469

SDD - Steam Generator Water/Steam Isolation and Dump System

Mr. H. N. Miller

-2-

February 23, 1973

SDD - Steam Generator Sodium Level Control and Cover Gas System
SDD - Steam Generator Water/Steam to Sodium Leak Detection System
SDD - Steam Generator Instrumentation and Control System
SDD - Steam Generator Reaction Relief System

CENC-1197 describes that work accomplished under the test model program and essentially consists of the evaporator, superheater and water/steam recirculating system components. The remaining associated steam generator systems design efforts were not completed and consequently are not included in the report. In addition, since work was terminated on developing the comprehensive follow-on program for design, fabrication, installation and testing of the test model, cost details for the program are not included. The design and fabrication schedules for the test model components have been adjusted to indicate start of the program on July 1, 1973, in an attempt to provide a realistic model delivery date for your planning purposes.

The above submittals completes all technical information required to be submitted as part of the subject contract both for information requested by the AEC and also that which CE previously scheduled for completion per Reference (2).

Sincerely yours,

A. A. Tuzes

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LMFBR STEAM GENERATORTEST MODELFEBRUARY 23, 1973CONTRACT AT(11-1)-3031LMFBR STEAM GENERATOR R&D

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1.0 Introduction

Combustion Engineering, Inc., has undertaken a contract for the design and development of safe and reliable LMFBR steam generators. The CE plan to develop the technology required to furnish the LMFBR industry with sodium heated steam generators is presented in CEND-355 "Report on Program Definition Phase for LMFBR Steam Generators".

In previous fiscal years, a reference steam generator was selected, preliminary design analyses were accomplished to verify the conceptual design, and experimental programs were conceptually designed, planned and initiated to provide for the successful development of the reference steam generator concept. The reference concept selected was a bayonet tube design. Results of these previous efforts are presented in the following reports: CEND-360, CEND 364, CEND 365 and Supplement , R & PD 960003-1, and CENC 1141. Additional information is presented in "Tube-To-Tubesheet Welding Development Program for LMFBR Steam Generator Development, Interim Report," dated December 20, 1972.

Subsequent efforts resulted in the selection of the reference concept design of a sodium heated steam generator for use in the first LMFBR Demonstration Plant. This redirection of effort towards the near term application resulted in selection of a forced circulation, separate shell, modular, bayonet tube steam generator concept. In addition, the associated steam generator systems were also conceptually designed to encompass a complete steam generating system. Results of these efforts are presented in CENC-1194, "LMFBR Demonstration Plant Steam Generating System", dated November 9, 1972, and Supplement to CENC-1194 dated February 23, 1973.

To further assist the AEC in evaluating the options available under the national LMFBR steam generator program, C-E also performed that work necessary to provide

a preliminary design and follow-on program for the detail design, fabrication, and test of a 30 Mwt model of the C-E steam generator concept for the first demonstration plant.

Also included were engineering efforts to propose modifications to existing SCTI System Design Descriptions and preliminary design of new SCTI systems along with appropriate specifications required for installation and testing of the C-E test model. Guidelines for the initial preliminary design task required that sufficient information be included such as to provide confidence to proceed with long lead material procurement and with detailed design/analysis under the follow-on program.

Combustion Engineering has terminated work under the subject contract prior to completion of the 30 Mwt test model preliminary design tasks. Accordingly, this report compiles that information completed prior to termination of work. The work remaining generally consists of the associated test model systems design tasks, and final development of the follow-on program. However, work was sufficiently completed to fully characterize the evaporator and superheater modules and also the steam/water recirculating system. Also included are the production planning, manufacturing, quality assurance and test planning efforts to compile the information being developed for the follow-on program into one report.

A master plan (ES-7670-10-0) has been developed which defines the major tasks and associated development programs necessary to design and fabricate the test model steam generator. The plan consists of detail design and analysis, procurement of materials and components, and fabrication and assembly of the steam generator components and the water/steam recirculation system. The master plan and also the associated design and fabrication schedules included in the report have been revised to provide for commencement of detail design and fabrication of the test model at

the start of Fiscal Year 1974.

The associated development programs necessary to support design and fabrication of the test model have been defined and may be found within separate correspondence under the subject contract. These programs consist of the following:

- Tube-To-Tubesheet Joint Development
- Shell Side Flow Distribution and Tube Vibration
- Materials Characterization
- Insulator Tube Characterization

A sodium heated thermal performance test to experimentally determine the bayonet tube heat transfer characteristics is also part of the overall development program and is being conducted under a separate company sponsored effort.

2.0 Test Program Objectives

2.1 Test Program Overall Objective

A preliminary test specification is included as Appendix C. This specification, "Steam Generator Testing in the SCTI" CE-EP-7670-3, lists the broad base program objectives as well as specific objectives of the individual tests proposed in the test specification.

Among the broad base objectives of the program are:

- To verify that the steam generator meets or exceeds the performance requirements specified in RDT E4-16T Ordering Data, CE-EP-7670-5.
- If the steam generator does not meet the requirements specified; to define any deficiencies thereof.
- To confirm that the mechanical design of the steam generators functions as required in an LMFBR system.
- To reduce any uncertainties pertaining to the operating characteristics of the steam generators and to assist in establishing various operating procedures.
- To enhance and expand the technological base for LMFBR steam generators.

2.2 Specific Test Objectives

In meeting the overall program objectives outlined above, some of the specific objectives to be gained during the actual test series at the SCTI include the following:

- Heat transfer performance, steady state and transient
- Control response
- Vibration characteristics
- Recirculation loop performance and characteristics
- Steam drum separator performance
- Confirmation of high temperature analytical techniques (Comparison of estimated versus measured stresses)
- Mechanical functional performance
- Optimum point for circulation ratio
- DNB (departure from nucleate boiling) in the evaporator

- Sodium side gas entrainment (carry under)
- Effects of fouling on heat transfer
- Sodium and water distribution and pressure drops
- Radial and axial sodium temperature profile in the evaporator and super-heater modules

2.3 Design and Manufacturing Objectives

In addition to those objectives listed above, and in the test specification, many additional benefits will be derived from the total program. The overall program begins with the preliminary design of a test model that is to demonstrate the adequacy of steam generators which are required to operate reliably over many years in a LMFBR system.

Sodium heated steam generators are one of the more critical components in a LMFBR system, and at the same time one of the most difficult to design because of the pressure boundaries between high temperature low pressure sodium and high pressure water/steam. Large temperature differences and rapid thermal transients within the steam generator add to the complexity of design and analysis. Problems encountered in the design and analysis of a steam generator model will be identical to those for full size system units and solutions to those problems for the model will be directly applicable to the plant components.

The fabrication of a ≈ 30 Megawatt model will provide experience that will prove extremely valuable in the later fabrication of LMFBR system steam generators. Stringent specification requirements for cleanliness, tolerances, welding and non-destructive testing are essential in providing the quality and reliability required for components such as these. The model steam generator will be manufactured under the same conditions and requirements as the production units.

Certain design features of the steam generator will require new equipment and fabrication techniques. These include the tube-to-tubesheet joint which requires in-

ternal bore automatic welding and radiography and other non-destructive testing equipment. Upon completion of the steam generator model manufacture, any new equipment techniques will have been adequately demonstrated.

2.4 Post Test Objectives

Upon completion of the test series at the SCTI, the steam generator system will be carefully dismantled and packaged for return to Combustion Engineering's shop at Chattanooga. Here the steam generator will be dismantled to expose areas of interest for evaluation. The dismantling of the steam generator will be accomplished in accordance with a program plan defining the requirements for the post test evaluation. The implementation of this plan will be closely monitored by cognizant personnel to ensure compliance with the requirements specified in the program plan. These requirements will be designed to eliminate or minimize influences or effects on the material other than those imposed by the test series.

Some of the specific tasks that will be performed during the post test series will be to measure and evaluate:

- Extent of corrosion, erosion
- Wear, fretting/abrasion at tube supports
- Dimensional changes
- Scale build-up
- Metallurgical (physical and chemical) changes of base, weld, and weld heat affected zone metals

The objectives of the post test examination:

- To reduce the uncertainties pertaining to the design of steam generators
- To expand knowledge of materials and their use
- To confirm or provide a new base for analytical techniques
- To expand the knowledge of failure mechanisms
- To expand the technological base for LMFBR steam generators

3.0 Steam Generator Evaporator and Superheater Modules

3.1 Design Description

This section describes CE's design for an approximately 30 MWt Sodium Steam Generator Model which is representative of CE's LMFBR Demonstration Plant Steam Generator Design.

3.1.1 Design and Operating Requirements

The design and operating requirements for the approximately 30 MWt Model are to be in accordance with Combustion Engineering's Ordering Data (Specification No. CE-EP-7670-2) which supplements RDT Standard E4-16T dated May, 1972. The steam generator described herein was designed to operate at the following conditions at 100% power:

Net Thermal Rating	25.0
Feedwater Flow Rate	$.903 \times 10^5$ lbs./hr.
Feedwater Temperature	460°F
Feedwater Pressure	2666 psia
Recirculation Ratio	3.5
Steam Outlet Pressure	2500 psig
Steam Outlet Temperature	900°F
Sodium Inlet Temperature	960°F
Sodium Flow Rate	$.989 \times 10^6$ lbs./hr.

3.1.2 Physical Description

3.1.2.1

The 30 MWt Sodium Steam Generator Model consists of two separate vessels, an evaporator and a superheater. The design of these components is shown on CE drawings SE-7670-1-1 (superheater), SE-7670-2-0 (evaporator), and SE-7670-3-0 (pressure boundary weld map). As shown on the drawings, the conceptual design arrangement of the evaporator and superheater components is identical. The differences between the evaporator and superheater are the overall lengths and diameters, number and length of tubes, material

thicknesses, etc.. For purposes of this description, the nomenclature used for the various parts of the steam generator is shown in Figure 3.1-1.

The evaporator and superheater are bayonet tube, removable tube bundle, vertically oriented, flange supported, shell and tube counter flow heat exchangers. Each unit is made up of two major subassemblies; the removable tube bundle assembly and the sodium shell assembly. The tube bundle assembly consists of the "bayonet" assemblies, high pressure (heat transfer) tubing, tube supports, tube bundle liner, high pressure tubesheet, high pressure shell, top head, and feedwater inlet (evaporator) steam outlet (superheater) plenum within the high pressure shell. The sodium shell assembly consists of the sodium shell, sodium inlet and outlet nozzles, nozzle thermal liners, and integral tube bundle lateral support keys in the shell.

When the two assemblies are joined into a complete unit, the closure between them is a pair of bolted and omega seal welded flanges located at the high pressure tubesheet/sodium shell junction.

The pressure boundary between the water/steam and the sodium is formed by the high pressure (heat transfer) tubes and the high pressure tubesheet, both a part of the removable tube bundle assembly. The high pressure tubes are welded to the high pressure tubesheet and the lower ends of the tubes are closed with a hemispherical cap.

Also welded to the high pressure tubesheet are the high pressure shell on the top side and the flange on the lower side that joins with the sodium shell. The high pressure shell contains a conventional flange at the top end to which is bolted a flat head. The seal at this joint consists of double self-energizing metallic O-rings. Leak monitoring will be provided between these seals. Suspended within the high pressure shell is the plenum to which the bayonet assemblies are attached. This is termed the feedwater inlet plenum in the evaporator and superheated steam outlet plenum in

the superheater. The top of the plenum is closed with a flat bolted cover plate.

The inlet/outlet pipe from this plenum extends into and forms a thermal liner for the inlet/outlet nozzle in the high pressure shell. The bayonet and insulator tubes are mechanically attached to the low pressure tubesheet that forms the bottom of this plenum. The bayonet assemblies extend from this plenum down through the high pressure tubesheet and into the high pressure tubes, and terminate just short of the closed lower end of the high pressure tubes. Boiling/superheating takes place in the annuli created by the O.D. of the insulator tubes and the I.D. of the high pressure tubes. The bayonet assemblies actually consist of two separate tubes, the inner and outer being termed the bayonet and insulator tube respectively. This is necessary to provide an insulating gap between the outer annulus where the heat transfer takes place and the inner tube in which the water or steam is conducted from or to the plenum in the channel. This insulating gap is required to reduce regenerative heat transfer between these flow paths. The high pressure (heat transfer) tube bundle extends down from the high pressure tubesheet into the sodium shell and terminates near the tangent of the bottom head in the sodium shell.

3.1.2.2 Flow Arrangement

Sodium flow is as shown on Figure 3.1-2 and is described as follows: Sodium enters the superheater through an inlet nozzle located in the bottom head of the superheater. The sodium then flows upward through the tube bundle and exits the bundle through "windows" in the baffle into the annulus created by the shell and baffle. The sodium then leaves the superheater through nozzles located in the upper end of the sodium shell. The sodium from the superheater is now pipe conducted to the top end of the evaporator where it enters through two nozzles, is distributed in the annulus through the "windows" and into the bundle. The sodium then flows downward through the tube bundle and exits through a nozzle in the bottom of the evaporator.

The water/steam flow through the evaporator, superheater and steam drum is as follows (See Figure 3.1-2): Feedwater enters the system through nozzles in the steam drum where it mixes with the separated water. This mixed water then leaves the drum and is pumped to the evaporator where it enters the plenum inside the high pressure shell at the top of the evaporator. Here the water is distributed to the double wall bayonet assemblies and flows downward to the bottom of the high pressure (heat transfer) tubes. The water then flows upward through the tubes. Evaporation takes place in each annulus as the water flows upward and the fluid enters the upper channel at a quality dependent upon the circulation ratio at that load level. The steam/water mixture rises upward around the plenum and enters a pipe connected to the outlet nozzle where it leaves the evaporator. The steam is now conducted through riser(s) to the steam drum. In the steam drum, the liquid is separated from the steam and is pumped by the circulating pump back to the evaporator. The dry saturated steam leaves the steam drum and is piped to the superheater where it enters the high pressure shell at the top end of the superheater. The saturated steam is conducted to the center of the shell by an elbowed pipe. The steam then passes downward around the plenum and enters the annuli created by the bayonet assemblies and high pressure tubes and flows downward in each annulus where it is superheated by the upward flowing sodium on the shell side. At the bottom end of the high pressure (heat transfer) tubes, the superheated steam turns and enters the bayonet tubes and flows upward through these tubes to the superheated steam outlet plenum within the top head of the superheater. The steam now leaves the superheater via a thermally lined nozzle in the side of the high pressure shell and is piped to the turbine.

The steam and sodium flow paths within the superheater and evaporator units offer one very important advantage, this advantage being that, except for the heat transfer tubes, all high pressure steam containing portions of these components, including

the critical tube-to-tubesheet attachment welds, tubesheets, high pressure snell, etc., operate at saturated steam temperatures (approximately 670°F) that are well below the critical material creep range.

3.1.2.3 Shell and Nozzle Thermal Liners

Snell and nozzle thermal liners are provided at the sodium inlet and outlet nozzles. The thermal liner at the bottom head and nozzle is attached to the nozzle. The liner is made in one piece, conforms to the shape of the hemispherical head, and extends upward into the shell. Vents are provided at the bottom of the liner for purging and sodium filling.

The shell and nozzle liners in the upper shell are in separate pieces. The cylindrical snell liner is supported at the mid plane of the nozzles and thermal growth will be up and down from that plane. The nozzle liners are attached to the crossover nozzles and fit through openings in the shell liner.

3.1.2.4 Tube-To-Tubesheet Joints - High Pressure (Heat Transfer) Tubes

The configuration selected for the critical tube-to-tubesheet joint is shown full size at the right. As can be seen, the end of the tube that is welded to the tubesheet is upset on the outside diameter to increase the wall thickness by one eighth of an inch. This thicker portion of the tube tapers down and is faired into the 1-1/2 inch O.D. of the tube. The tapered portion of the tube is approximately 3/4 inch long.

The weld preparation on the tubesheet is machined into a weld deposited cladding overlay that is added to the tubesheet to insure that the metallographic structure is free of any laminations, and to closely control the chemistry and grain structure. The prepared end of the tube and tubesheet is subjected to full volumetric and surface examination prior to welding. The final configuration of the welded joint places the actual weld and heat effected zones in a thickness that is approximately 75% thicker than the average tube wall thickness below the weld.

The tube-to-tubesheet attachment joints for the evaporator and superheater tubes to the high pressure tubesheets are internally welded in the vertical position. The first pass in this weld is a gas-tungsten-pulsed arc melt pass that fuses the closely machined weld prep between tube and tubesheet. Two or more additional filler passes are required. The inside surface of the welds are then reamed to a uniform I.D.

3.1.2.5 Bayonet Assembly Attachment

The double walled bayonet assemblies are attached to the low pressure plenum tubesheet. The ends of these tubes are flared to match machined tapered holes in the low pressure tubesheets. The tubes are fixed in place and sealed with threaded and tapered fittings that are inserted into the threaded holes in the tubesheet. The fittings are staked to the tubesheet to prevent loosening during operation.

3.1.2.6 Tube Supports

The primary tube supports for the high pressure (heat transfer) tubes are commonly called "eggcrates". The eggcrate assembly is fabricated from flat bars welded into a grid matching the triangular pitch of the tubes. All bar intersections are seal welded to eliminate crevices. The bars are cut from cold rolled strips that have rounded edges and all corners will be deburred and polished. The eggcrate assemblies are attached to the bundle flow liner with flexible attachments

that allow differential thermal growth between support and liner. A typical eggcrate assembly is shown on CE Dwg. E-244-600-0.

3.1.2.7 Support Between High Pressure Tube and Bayonet Tubes

The bayonet assemblies inside the high pressure tubes must be supported by spacers between the tubes. This support is provided by shouldered pins that are press fit into holes drilled in the insulator tubes. The ends of these spacer pins bridge the heat transfer annuli and insulator gaps and provide support for the bayonet and insulator tubes. The ends of the pins are rounded and polished to prevent crazing or galling of the high pressure heat transfer tube.

3.1.2.8 Baffle

The baffle closely surrounds the tube bundle from the high pressure tubesheet to below the bottom end of the high pressure tubing. The high pressure tube support eggcrates are attached to the inside of this baffle and all loadings are transmitted into the baffle. Lateral support for the tube bundle is provided by keys on the shell that engage keyways machined into rings that are an integral part of the baffle. The baffle is keyed to the shell near the bottom end and at approximately the midpoint of the tube bundle. The top end of the baffle is attached to the tubesheet. Supporting the baffle at the tubesheet and keying at midpoint and bottom allows differential thermal growth between shell and baffle while maintaining concentricity and preventing rotation of the bundle within the shell. Axial and radial differential thermal growth is accommodated. Two sets of "windows" are cut into the baffle at the top end of the heat transfer length of the tubes. The top set of windows is located in the gas space to provide a path for sodium water reaction pressure and by-products to the relief nozzles that are also located in the gas space above the sodium surface. The lower set of "windows" in the baffle are located below the sodium free surface and sodium enters or leaves the tube bundle through these windows (depending upon the unit). The window location below the sodium

surface should result in a quiet sodium surface and a reduction of gas entrainment. The size and orientation of these windows result in sodium velocities of less than two (2) feet per second. The sodium crossover nozzles from the superheater to the evaporator are located 180° apart and are two (2) feet below the lower edge of the windows in the liner. Sodium leaving the superheater bundle passes through the windows, flows downward, splits and leaves the superheater through the two crossover nozzles. Sodium entering the evaporator impinges on the baffle, splits and then rises in the annulus and flows through the windows into the tube bundle.

3.1.2.9 Sodium Bypass Seal

A seal must be provided in the annulus between the shell and bundle liner to prevent significant sodium bypass. This seal must accomodate differential axial and radial thermal growth between the parts and must also seal against differential pressure between inlet and outlet nozzles. This seal is accomplished by using an inactive flow restrictor (Labyrinth type seal) in the annulus below the crossover nozzles.

3.1.3 Materials

The materials selected for use to fabricate the evaporator and superheater modules of the 30 Mwt model are as follows:

Tubing---For high pressure (heat transfer) tubing and bayonet and insulator tubes: Material - SA-213-T9, RDT M3-2T

Plate----For pressure boundary shells, support skirt and base plate and steam side internals: Material-SA-387, Gr. D annealed, RDT- M5-5T.

Plate----For baffle, sodium side thermal liners, and eggcrates: Material - SA-240, Type 405, RDT M5-1T (Modified 1/2% Molybdenum).

Forgings---For tubesheet, flanges, top head and nozzles:

Material-SA-182 F22, RDT M2-2T

NOTE: See CE Dwg. SC-7670-4-0 (superheater) and SC-7670-5-0 (Evaporator), "Tubesheet Ring Forging Ordering Sketches".

These are the most critical items to CE's fabrication schedule (See 3.4.3.1).

Bolting-- Material: SA-193, Gr. B7, RDT M6-3T.

"O" Rings---Material - Inconel.

COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. _____

DESCRIPTION 30MW Model Nomenclature

NUMBER Figure 3.1-1

SHEET _____ OF _____

DATE 2/2/73 BY 4E2

CHECK DATE 2/13/73 BY 84P

FIG 3.1-2

SCHEMATIC FLOW ARRANGEMENT
OF BAYONET TUBE STEAM GENERATOR

3.2 Thermal-Hydraulic Design

3.2.1 Sizing

The 30 MW steam generator is a scaled down version of the 110 MW LMFBR Demonstration Plant steam generator described in CE Report CENC 1194, dated November, 1972. To provide a 20% overload capability, a 100% load MW rating of 25 was chosen. The number of tubes for the superheater and evaporator were:

$$\frac{25}{110} \times 170 = 39. \quad \text{Superheater}$$

$$\frac{25}{110} \times 390 = 89. \quad \text{Evaporator}$$

In order to make the tube bundles symmetrical, the number of tubes chosen was:

Superheater - 37

Evaporator - 91

With the tube bundle geometries chosen, the sizing computer programs were used to establish the bundle length. The results of the sizing are given below:

Superheater Bundle Length - 32.4 ft.

Evaporator Bundle Length - 31.1 ft.

The operating temperatures and pressures for the model are approximately those of the Demonstration Plant steam generator.

3.2.2 Heat Transfer

After the final steam generator configuration was chosen, a study was made to investigate the performance of the steam generator model at loads of 100%, 80%, 60%, and 40%. The following ground rules were established for these part load studies:

1. The variation in feedwater temperature with load was established based on data obtained through turbine manufacturers.
2. The feedwater is added to the saturated water in the steam drum at a flow rate that maintains the water level in the drum.

3. Flow rate through the evaporator is constant at all loads. This permits the use of a constant speed recirculation pump.

4. Steam generator sodium ΔT is allowed to vary at part load so that superheated steam outlet pressure and temperature are held constant.

Therefore, percent load is defined as percent steam flow.

Figure 3.2-1 is a curve of feedwater temperature versus load as established by the ground rules for part load performance. The evaporator flow (WE) and steam flow to the superheater (WSE) are plotted in figure 3.2-2, and recirculation ratio, $\frac{WE}{WSE}$, is plotted in figure 3.2-3 as a function of % load. The remaining figures in this section are the results of the part load performance computer runs. Given as a function of percent load are evaporator and superheater water/steam side pressure drop (Figure 3.2-4) and sodium flow, inlet temperature, and ΔT (Figures 3.2-5 and -6). Heat flux versus distance below the sodium level is plotted in Figure 3.2-7 for the 100% load case. Figures 3.2-8 through 3.2-15 are temperature distribution plots for the evaporator and superheater at 100%, 80%, 60%, and 40% loads.

It may be concluded from this study that the steam generator model, as designed, will operate at steady-state part-load conditions at a reasonable variation in sodium ΔT (287°F at 100% load to 284°F at 40% load). In addition, performance of the sodium test model will be very similar to that of the demonstration plant steam generators.

FIGURE 3.2-1
FEEDWATER TEMPERATURE

FIGURE 3.2-2
EVAPORATOR
STEAM/WATER FLOW

FIGURE 3.2-3
RECIRCULATION RATIO

FIGURE 3.2-4
SUPERHEATER AND EVAPORATOR
PRESSURE DROP

SODIUM FLOW - LBS./HR. $\times 10^{-6}$

FIGURE 3.2-5
SODIUM FLOW

PERCENT LOAD

FIGURE 3.2-6
PART LOAD SODIUM TEMPERATURES

FIGURE 3.2-7
HEAT FLUX AT 100% LOAD

FIGURE 3.2-10
TEMPERATURE DISTRIBUTION
EVAPORATOR AT 20% LOAD
CR = 4.375

FIGURE 3.2 - 11
TEMPERATURE DISTRIBUTION
SUPERHEATER AT 80% LOAD

FIGURE 3.2 - 13
TEMPERATURE DISTRIBUTION
SUPERHEATER AT 60% LOAD

FIGURE 3.2-15

TEMPERATURE DISTRIBUTION
SUPERHEATER @ 40% LOAD

RBC

3.3 Mechanical Design Analysis

3.3.1 Tubesheet/Flange Sizing

A detailed finite element analysis of the evaporator tubesheet/sodium flange region was completed for design pressures. The maximum primary bending stress occurred in the perforated tubesheet at the centerline of the vessel. The calculated stress intensity of 15.4 ksi is less than the allowable stress of $1.55_m = 28.6$ ksi at 650°F. All stresses meet the appropriate allowables of the ASME Code, Section III for Nuclear Vessels.

The geometry of the superheater is similar to that of the evaporator; consequently, the results of this analysis may be qualitatively applied to the superheater.

Based on considerations of vessel diameters, tubesheet thicknesses, and design pressures, it is anticipated that the primary stresses in the superheater will meet the appropriate allowables of Section III.

The detailed analysis can be found in Appendix E-1.

3.3.2 Evaporator and Superheater Steam Side Sizing

Presented in this analysis are the ASME code justifications for the basic dimensions of the evaporation side of the sodium to water steam generator for the 30 MW demonstration plant. The stresses considered are those resulting from design pressure and design temperature. The stresses determined meet the general primary membrane stress intensity allowables of the ASME Boiler and Pressure Vessel Code, Section III, Nuclear Vessels.

The detailed analysis can be found in Appendix E-2.

Presented in this analysis are the ASME code justifications for the basic dimensions of the superheater side of the sodium to water steam generator for the 30 MW demonstration plant. The stresses considered are those resulting from design pressure

and design temperature. The stresses determined meet the general primary membrane stress intensity allowables of the ASME Boiler and Pressure Vessel Code, Section III, Nuclear Vessels.

The detailed analysis can be found in Appendix E-2.

3.3.3 Tube to High Pressure Tubesheet Joint

This analysis presents the preliminary structural evaluation of the pressure tube to high pressure tubesheet weld. Stresses considered are those resulting for steam side design pressure, sodium side pressure, and forced displacement of the tubeweld due to tubesheet deflection under design loading.

This analysis is made in accordance with the 1971 ASME Boiler and Pressure Vessel Code, Section III, for Nuclear Power Plant Components and includes Addenda through Summer, 1972.

See Appendix E.3 for detailed analysis.

3.3.4 Tube at Sodium-Argon Interface

The purpose of this analysis is to examine the high pressure tube at the sodium level in the steam generator, and determine if any inelastic deformation occurs. It is shown in this report that inelastic deformation does occur (See Sheet 14), and an attempt was made to calculate the incremental plastic strain using a simplified conservative method, the full relaxation Bree method. The Bree method proved, however, to be too conservative and the recommendation of this report is to perform a more rigorous inelastic calculation.

See Appendix E.4 for detailed analysis.

3.4 MANUFACTURING

3.4.1 INTRODUCTION

In order to fabricate the components parts of model steam generator it is necessary to have: (1) A Quality Assurance Plan which provides the assurance that the design, fabrication, material procurement and inspection will meet the specification requirements. This is described in section 3.4.2. (2) An Engineering Plan which provides for the orderly design and analyses of the individual components and overall system so that customer approval of the design, material selection, fabrication procedures is obtained and material procurement is released as required by the fabrication schedules. Section 3.4.3 describes the Engineering Plan to accomplish this. (3) A Manufacturing Plan for the fabrication of the components. This consists of Integrated Manufacturing Quality Plans and schedules which are included in section 3.4.4 As a part of the manufacturing plan Weld Qualification covered in section 3.4.4.3.

Section 3.4.5 briefly describes the preparation for shipment of the individual superheater and evaporator modules.

3.4.2 Quality Assurance Program Plan

In keeping with the AEC's general requirements and philosophy of providing a total quality assurance program from conceptual design and development through the various stages of the procurement of material and equipment, fabrication and installation of components, to operation of the facility. Combustion Engineering, as the fabricator of reactor development and test facility components, has established and implemented quality assurance procedures to satisfy the requirements set for RDT F2-2T and other applicable standards and codes.

3.4.2 Quality Assurance Program Plan Cont'd

The management and planning quality assurance activities are accomplished through two levels of Quality Assurance; (a) the first level of Quality Assurance rests with the organization responsible for design and development; procurement; manufacturing and construction. Personnel in each organization are assigned responsibilities for the preparation of quality assurance program plans, procedures, audits and reviews, and the preparation of quality status reports. Quality assurance activities are conducted in accordance with established schedules, procedures and check lists. (b) the second level of quality assurance, defined as Quality Surveillance, is performed by Manufacturing Services Quality Assurance (MSQA). MSQA is responsible for providing surveillance to assure that each phase of the program is in compliance with the procedures and agreements set forth in C-E's Quality Assurance Program Plan. The results of MSQA's audits are forwarded to the Vice-President of Combustion Division through the Director of Manufacturing Services. Project management organization is shown on Figure 3.4-1.

Design and Development Activities are conducted in accordance with established procedures and practices by functional engineering departments. Independent design reviews are performed to assure that applicable design criteria, codes, standards, practices and other requirements have been satisfied. Interface is provided for by joint meetings of participating organizations.

Procurement quality assurance activities are controlled through written procedures which assure that qualified suppliers are selected, that procurement documents contain accurate and complete ordering specifications and that the "as received" products are, in fact, in accordance with the applicable specifications.

Manufacturing, fabrication and assembly activities are controlled by means of an Integrated Manufacturing Quality Plan (IMQP), and the Quality Assurance Program Plan. This program consists of a Quality Assurance Manual, with Revisions as re-

3.4.2 Quality Assurance Program Plan Cont'd

quired by the RDT Standards, material and process specifications covering shop operations and non-destructive testing, and fabrication procedures complying with the RDT specifications. The plan is reviewed and signed off by the Quality Assurance and approved by the Project Manager. The Quality Assurance Manual explains the scope, functions and responsibilities in the areas of material procurement, fabrication, non-destructive testing, internal and external audits and shop and vendor inspections and records.

Program effectiveness, internally and externally, will be reported through the Project Manager. The functional quality assurance organization is shown on Figure 3.4-2.

A detailed quality assurance program plan noting Combustion Engineering interpretations will be submitted at a later date.

3.4.3 Engineering Plan

The engineering plan provides a logical sequence of performing design, analyses, material requisition and fabrication releases to meet the needs of the Manufacturing plan 3.4.4. This plan which schedules the work, is graphically shown on drawings ES-7670-1-3 and ES-7670-5-1.

3.4.3.1

The Design engineering schedule shown on ES-7670-1-3 outlines the design phases involving design engineers and drafting personnel in the preparation of fabrication drawings, requisitioning materials, releasing fabrication and manufacturing follow-up to the completion and shipment of the model components. Included in this schedule are the design and analytical efforts performed by other engineering groups within the division, which are needed to fabricate the Water/Steam Circulation System described in section 3.5.

3.4.3.2

The Analytical schedule drawing, ES-7670-5-1, programs the required analyses in order to verify and justify the design.

3.4.3.3

All fabrication drawings, analyses, and procedures are submitted to the customer for approval and any comment will be resolved prior to the release of any material requisition or fabrication.

3.4.4 Manufacturing Plan

The manufacturing plan consists of an Integrated Manufacturing Quality Plan and a Manufacturing Schedule.

3.4.4.1

Manufacturing schedules are prepared to show the major subcomponents that become the final product and their relationship to each other in the fabrication sequence. The schedule specifies when each department within the company must complete its task in order to meet the required shipping date.

Three schedules are included as tabulated below:

ES-7670-7	Evaporator Module Schedule
ES-7670-8	Superheater Module Schedule
ES-7670-9	Steam Drum and Piping Schedule

3.4.4.2

Integrated Manufacturing Quality Plan (IMQP) describes the sequence to be followed in fabricating a component and lists all inspections and quality witness and hold points during the work. The IMQP is submitted to the purchaser for review and for the addition of the purchaser's witness and hold points. These witness and hold points are then incorporated into the plan. Using the IMQP and engineering drawing, "travellers", which describe in detail each operational step for use at

3.4.4.2 Cont'd

each work station are prepared.

Two IMQP's are enclosed:

Appendices D. 1 and D.2 the first being for the evaporator and super-heater modules and the second for the recirculation water components, i.e., the steam drum and associated piping.

3.4.4.3 Welding Qualification Plan

The welding qualification plan program is designed to ensure that weld procedures used for fabrication will be qualified in accordance with RDT standard F6-5T for the materials of construction.

Weld procedure qualifications will be made for joining of forgings to forgings such as the high pressure tubesheet to the tubesheet flange, forgings to plate, for attachment of the tubesheet flange to the shell, plate to plate for making longitudinal and circumferential welds in shell courses.

After each procedure is qualified, a procedure will be written for manufacturing use and shop personnel qualified to use these procedures.

Welds will be qualified in sequence as required by the production schedule and the qualification schedule is shown on Drawings ES-7670-7 and ES-7670-8.

The following procedure qualifications will be made as tabulated below.

Procedure	Base Materials	Thickness(Min.)	Welding Position	Electrode
SMA	M2-2T to M2-2T	4"	2G	M1 - 4T
SMA	M2-2T to M5-5T	4"	2G	M1 - 4T
SMA	M5-5T to M5-5T	3"	2G	M1 - 4T
SMA	M3-12T to M3-12T	1"	2G	M1 - 4T
SMA	M3-12T to M5-5T	1"	2G	M1 - 4T
SMA	M5-1T to M5-1T	1"	2G	M1 - 1T
SMA	M5-1T to M2-2T	1"	2G	M1 - 4T M1 - 10T
SMA	M2-2T to M3-1T	1"	2G	M1 - 3T
SMA	M2-2T to M2-2T	1"	2G	M1 - 1T
SMA	M5-5T to M5-1T	1"	2G	M1 - 4T M1 - 10T
SMA	M2-2T Cladding		2G	M1 - 1T
SMA	M5-5T Cladding		2G	M1 - 1T

Procedure	Base Materials	Thickness (Min.)	Welding Position	Electrode
SAA, GTA	M2-2T to M5-5T	4"	1G	ER-521 (No RDT Spec.)
GTA	M5-1T to M5-1T	1/2"	2G	M1 - 1T

3.4.5 Snipping

3.4.5.1

The superheater and evaporator modules after final inspection will be sealed and filled with a dry inert gas. The gas system is designed to maintain a small positive internal pressure within the module. A gas supply will accompany the modules, and will provide a constant supply of gas regulators and flow meters to make up any leakage.

3.4.5.2

The module will be mounted as shown on drawing C-63673025-0 on three supports. The support at the lower end of the module is designed so that the module can be rotated on a trunion into the vertical position for field erection. A lifting beam is attached to the steam side head for attachment of a crane hook for both rotation of the module from the horizontal to the vertical position and also for sitting the module on its foundation in the SCTI test loop.

3.4.5.3

The three supporting frames are designed for mounting on a rail car for shipment.

FUNCTIONAL ORGANIZATIONAL CHART FOR PROJECT MANAGER

FIGURE 3.4-1

FIGURE 3.4-1

ORGANIZATION CHART
FOR
QUALITY ASSURANCE OF
LMFBR PROJECT

3.5 WATER/STEAM CIRCULATION SYSTEM

3.5.1 WATER/STEAM CIRCULATION SYSTEM DESCRIPTION

3.5.1.1 SUMMARY DESCRIPTION

The Steam Generator Water/Steam Circulation System (SGWCS) produces high pressure superheated steam (approximately 2550 psig and 900°F) to the existing SCTI de-pressurization and desuperheating system in the following manner:

- (1) Feedwater is fed to the steam drum and recirculated with the boiler water by the recirculating pump to the evaporator.
- (2) In the evaporator, heat is transferred from the sodium to water where it becomes partially vaporized.
- (3) The resulting water/steam mixture then enters the steam drum where it is separated into steam and saturated water.
- (4) The saturated water is recirculated with the incoming feedwater; the saturated steam is passed through the superheater where it is superheated to the above conditions.

3.5.1.2 SYSTEM ARRANGEMENT

A. The SGWCS piping arrangement makes use of C-E standard Controlled Circulation boiler design parameters.

- (1) Height of steam drum above the recirculation pump allows the design to meet all NPSH requirements.
- (2) Flexibility has been provided in the piping where required.

B. The following SGWCS arrangement information is found in Addendum "C".

- (1) A system flow diagram (Dwg. No. 07670-1E0314).

(2) Four (4) pressure part arrangement drawings.

(a) Dwg. No. 07670-1F0109

(b) Dwg. No. 07670-1F0119

(c) Dwg. No. 07670-1E0131

(d) Dwg. No. 07670-1E0132

(3) Two (2) general arrangement drawings.

(a) Dwg. No. 07670-1E0303

(b) Dwg. No. 07670-1E0305

(4) A two page summary of pressure parts - number, size, and material.

3.5.1.3 DETAIL SYSTEM DESCRIPTION

The flow path is as follows (see Addendum "C" for drawings and pressure part size listing):

- A. Feedwater flow is brought to the 60" I.D. steam drum from the existing 6-5/8" O.D. feedwater line system. It is distributed evenly throughout the drum length and mixes with the boiler water contained in the drum.
- B. The mixture leaves the drum through the 8-5/8" O.D. downcomer.
- C. The mixed fluid enters the circulating pump suction and is discharged through the 8-5/8" O.D. discharge line and a flow control valve to the evaporator where the fluid is heated to the design water/steam mixture.
- D. The water/steam mixture then leaves the evaporator through the 8-5/8" O.D. outlet line to the 12-3/4" O.D. evaporator outlet distribution header where the mixture is delivered uniformly over the drum length by means of 6-5" O.D. tubes.

- E. The water/steam mixture enters the C-E standard Controlled Circulation 60" I.D. drum internals where it is separated into steam and saturated water.
- F. The separated boiler water is reservoiried in the drum and mixes with the incoming feedwater and the resulting mixture begins the recirculation flow path just described.
- G. The saturated steam proceeds through 3 - 3-1/2" O.D. tubes to a 10-3/4" O.D. collecting header from where it is delivered to the superheater by way of a 6-5/8" O.D. inlet line.
- H. The superheated steam discharges from the superheater through a 8-5/8" O.D. line to the existing SCTI depressurization and desuperheating system.

3.5.1.4 SYSTEM PERFORMANCE CHARACTERISTICS AND GENERAL FEATURES

- A. The one (1) circulating pump provides boiler circulation which is free from natural circulation effects and predictable over the load range with a desired circulation ratio of 3.5 at maximum continuous rating (MCR). However, the pump design point has been based on the maximum desired circulation ratio of 4.0 at maximum continuous rating.
- B. A flow control valve (installed in the 8-5/8" O.D. pump discharge line) has been provided to give the flexibility of varying the circulation ratio from 2.0 to 4.0 within the recirculation loop at a given load. This feature provides the opportunity of determining the most optimum flow (circulation ratio) to the evaporator during any given load test.

- C. There is also the added flexibility of providing orifice pressure drop (20 psi at the maximum desired circulation ratio of 4.0 at maximum continuous rating) in the evaporator inlet to adjust for final distribution requirements and to add stability to heated circuitry if it is required.
 - D. To insure the desired flexibilities outlined in Item B and C above, the pump design point has been selected for the following maximum design conditions:
 - (1) Maximum continuous rating (MCR).
 - (2) Circulation ratio of 4.0.
 - (3) 20 psi evaporator inlet orifice drop.
 - (4) Flow control valve in the full open position.
 - E. The system makes use of a 60" I.D. Controlled Circulation C-E steam drum with standard internals which have been proven on presently operating units at the same pressure and temperature conditions.
 - F. The pump does not have a suction nor discharge valve since the test model concept and philosophy does not warrant their purpose and use.
 - G. The system has quick closing (approximately 1 second) isolation valves in the inlet and outlet of both the evaporator and superheater to quickly isolate those components and dump the water and steam from them in the event of a water to sodium tube side leak.
- The analysis report of the water/steam dump system is covered later.

3.5.1.5 DESIGN PARAMETERS

The operating data, design information, and preliminary sizing of the SGWCS are found in Addendum "A".

3.5.1.6 COMPONENTS

3.5.1.6.1 PIPING

SGWCS pipe sizing and arrangement have been established by stress, hydraulic analysis, and operational requirements. Piping design and material are consistent with service requirements.

3.5.1.6.2 STEAM DRUM

A. There is one steam drum in the SGWCS.

(1) See Addendum "C" for the drum arrangement drawings.

B. The primary function of the steam drum is to receive the steam/water mixture from the evaporator and with the steam/water separating equipment installed, separate the water from the steam, therefore providing steam of acceptable purity to the superheater and sub-cooled water to the downcomer.

The separation equipment to perform the operation is collectively known as the drum internals. It consists of a primary and secondary separator and a corrugated plate dryer. The primary/secondary separator assemblies are a standard and have been used successfully in about 200 Controlled Circulation boilers. The corrugated plate dryer has been used for over ten years.

The 60" diameter drum is 6-1/2 feet long between head-shell welds and is equipped with two rows of primary/secondary

B. CONT'D

separator assemblies and a corrugated plate dryer. Each row of separators has 3 assemblies on 18-1/2 centers. For the maximum steam flow of 133,000 lbs/hr, each assembly is rated at 22,166 lbs/hr. The steam release per foot of drum length is 20,450 lbs/hr. These ratings are within limits of operating Controlled Circulation boilers and assure satisfactory performance.

To assure maximum effectiveness in drum internals performance, uniform flow distribution is accomplished by considering the flow and locations of risers, downcomers, steam outlets, and feedwater piping. The drum will have risers comprised of two (2) rows with an equal number of risers in each row. There will be three steam outlets in a single row, one (1) downcomer and one (1) feedwater inlet nozzle; all are located to provide the desired distribution.

A feature of the drum internals arrangement is the shroud baffle in the drum which directs the steam/water mixture from the risers to the separation equipment. This flow pattern minimizes metal temperature gradients during transient operation conditions.

- C. Basic operating and design parameters for the steam drum of the SGWCS are at MCR:

C. CONT'D

	<u>100% Load Design Conditions</u>
(1) Saturated steam flow - lbs/hr (rounded)	133,000
(2) Drum operating pressure - psig	2,700
(3) C.R.	4.0
(4) Entering feedwater temperature - °F	460

3.5.1.6.3 RECIRCULATING PUMP

A. There is one recirculating pump in the SGWCS.

- (1) See Addendum "C" for the circulating pump flow diagram (Dwg. No. 07670-1E0400) showing a typical arrangement of the pump and miscellaneous piping.

B. A wet motor or a canned motor pump will be supplied.

C. Basic operating and design parameters for the pump are:

	<u>100% Load Design Conditions</u>
(1) C.R.	4.0
(2) Flow - gpm	1700
(3) Head - feet	260
(4) Head - psi	71
(5) Fluid Temperature - °F	645
(6) Specific Gravity of Fluid	0.633
(7) Pump Suction Pressure - psig	2713

3.5.1.6.4 FLOW CONTROL VALVE

A. There is one flow control valve in the SGWCS.

B. The flow control valve installed in the 8-5/8" O.D. pump discharge line is used to vary the circulation ratio from

B. CONT'D

2.0 to 4.0 within the recirculation loop at a given load. The throttling service on the valve will be governed by the load point, desired circulation ratio, desired evaporator inlet orifice pressure drop, and the available pump head at the operating load point.

C. As an example, the approximate design parameters for the control valve at 100% load conditions are as follows:

	<u>Minimum Flow</u>	<u>Normal Flow</u>	<u>Maximum Flow</u>
Fluid Flow - gpm	550	1450	1700
Valve ΔP - psi	90	40	5

3.5.1.6.5 EVAPORATOR

A. There is one (1) evaporator in the SGWCS.

(1) C-E evaporator heat exchanger design details are found in Section 3.0 of the Test Model Design Report.

(2) Bayonet tube nomenclature is also presented in Section 3.0.

B. The evaporator is designed as a shell and bayonet tube counter-flow heat exchanger. The evaporator is a vertically oriented, removal tube bundle, and flanged supported design. Sodium flow is directed to the shell side. Heat is transferred from the hot sodium to the water to produce a saturated water/steam mixture. The evaporator, consists of two major sub-assemblies; the removal tube bundle assembly and the sodium shell assembly. The tube bundle assembly consists of the bayonet assemblies, high pressure (heat transfer) tubing, tube supports, tube

B. CONT'D

bundle liner, high pressure tube sheet, channel shell, channel cover, and feedwater inlet plenum within the channel. The sodium shell assembly consists of the sodium shell, sodium inlet and outlet nozzles, nozzle thermal lines, and integral tube bundle lateral support keys in the shell. The dual assemblies are joined into a complete unit by a pair of bolted and seal welded flanges located at the high pressure tube sheet/sodium shell junction.

The pressure boundary between the water/steam and the sodium is formed by the high pressure (heat transfer) tubes and the high pressure tube sheet, both a part of the removal tube bundle assembly. The high pressure tubes are welded to the high pressure tube sheet and the opposite ends of the tube are closed with a hemispherical cap.

Suspended within the channel is the plenum to which the bayonet assemblies are attached. This is termed the feedwater plenum. The bayonet assemblies extend from this plenum down through the high pressure tube sheet and into the high pressure tubes, and terminate just short of the closed lower end of the high pressure tube. Boiling takes place in the annuli created by the O.D. of the insulator tubes and the I.D. of the high pressure tubes. The bayonet assemblies actually

B. CONT'D

consist of two separate tubes, the inner and outer being termed the bayonet and insulator tube, respectively. This is necessary to provide an insulating gap between the outer annulus where the heat transfer takes place and the inner tube in which the water is conducted from the plenum in the channel.

- C. Mixed water enters the plenum inside the channel at the top of the evaporator. Here the water is distributed to double wall bayonet assemblies and flows downward to the bottom of the high pressure, heat transfer tubes. The water then flows upward through the Concentric annuli created by the insulator and high pressure tubes. Evaporation takes place in each annulus as the water flows upward and the fluid enters the upper channel at a quality dependent upon the circulation ratio at the load level. The steam/water mixture rises upward around the plenum and enters the pipe connected to the outlet nozzle to relieve the evaporator.

- D. Basic design parameters for one evaporator at MCR are:

	<u>100% Load Design Condition</u>
(1) Net normal rating - Mwth	
(2) Saturated steam flow - lbs/hr	133,000
(3) Inlet pressure - psig	2767
(4) Inlet mixed water temperature - °F	645
(5) Circulation ratio C.R. at outlet	4.0
(6) Feedwater inlet temperature - °F	460

3.5.1.6.6 SUPERHEATER HEAT EXCHANGER

- A. There is one (1) superheater in the SGWCS.

The design of the superheater is similar to the evaporator design - a shell and bayonet tube counter-flow heat exchanger.

- (1) For the superheater design details, see Section 3.0.

- B. The general design and concepts are approximately the same as the evaporator except as noted:

- (1) The flow of steam through the superheater is designed to flow in an opposite direction compared to the evaporator flow.

- (2) Heat is transferred from the sodium to saturated steam to provide superheated steam.

- C. Dry saturated steam enters the high pressure channel at the top of the superheater. In entering the channel, the saturated steam is conducted to the center of the channel by elbowed pipe. The steam then passes downward around the plenum and enters the annuli created by the bayonet assemblies and high pressure tubes and flows downward in each annulus where it is superheated by the upward flow of sodium on the shell side. At the bottom end of the high pressure (heat transfer) tubes, the superheated steam turns and enters the bayonet tubes and flows upward through these tubes to the superheated steam outlet plenum within the top of the superheater. The steam leaves the superheater via thermally lined nozzle.

D. Basic design parameters for one superheater at MCR are:

	100% Load Design Conditions
(1) Net thermal rating - Mwth	
(2) Steam flow rate - lbs/hr	133,000
(3) Superheated steam outlet temperature-F	900
(4) Steam pressure at SH outlet - psig	2550

3.5.1.6.7 QUICK CLOSING ISOLATION VALVES

- A. There are two (2) quick closing isolation valves for the evaporator and two (2) quick closing isolation valves for the superheater.
- B. The purpose of the valves is to quickly isolate the evaporator and superheater modules and dump the water and steam from the modules through a dump system in the event of a water to sodium tube side leak within the modules.
- C. The basic operating and design parameters for the specified quick closing isolation valves are:

	100% Load Design Conditions	
	<u>EVAPORATOR</u>	<u>SUPERHEATER</u>
C.R.	4.0	-
Flow - lbs/hr	532,000	133,000
Specific Volume of Fluid Inlet/ Outlet - ft ³ /lb	0.0254 0.0505	0.11063 0.2585
Valve ΔP - psi	3.0/2.5	5.0/30.0
Closing Time - seconds	1	1

3.5.1.7 MODEL DESIGN VERSUS DEMONSTRATION PLANT DESIGN

The following are the major component design differences in the test model SGWCS from those of the demonstration plant SGWCS:

- A. There is only one (1) recirculating pump in the test model SGWCS. Unlike the demonstration plant, no spare pump is provided since the short duration of time required to operate the test model and the quick availability of spare parts (if they were ever needed) for the size and type of pump do not warrant the provision of a spare pump.
- B. The pump does not have a suction valve nor a discharge valve. Since there is only one (1) pump furnished, there is no requirement to provide a pump isolation feature in the event of needed pump repair with the test model in operation. The same concept and philosophy outlined in item A above is also related to the deletion of the suction valve and discharge valve around the pump.

However, for the demonstration plant where the unit has to be maintained in operation while a pump is out of service for repairs, the pump isolation feature has been provided.

- C. For the purposes of testing the effects of flow over the desired range of circulation ratio from 2.0 to 4.0, the test model utilizes the most convenient application of a flow control valve to vary the flow. This flow control valve is installed in the pump discharge line.

The demonstration plant, due to its much narrower range of design circulation ratio requirements (3.5 to 4.0 at MCR) uses orifice pressure drop installed at the pump discharge line as the

flow control device. This orifice can be easily removed or adjusted to increase the circulation ratio within the desired limits set forth in the design.

- D. In the SGWCS for the test model, the material for the steam drum and system piping is SA-387-D normalized and tempered for plate and SA-335 P-22 for piping. These materials are provided as a "recovery defense" against the up transients that could occur in the event of the "double jeopardy accident" of a simultaneous loss of feedwater and a failure of the quick closing isolation valves from closing causing the system to "boil dry".

The demonstration plant which is provided with an emergency feedwater supply which can be used in the above occurrence, need only to have carbon steel (SA-106-C and SA-515-70) in its SGWCS with the exception of the high temperature superheater outlet steam side.

3.5.1.8 SGWCS SUPPLEMENTARY SYSTEMS (WATER/STEAM SIDE)

3.5.1.8.1 WATER/STEAM ISOLATION AND DUMP SYSTEM

- A. In the event of a water to sodium tube leak, the evaporator and superheater modules can be isolated by the inlet and outlet quick closing isolating valves (closing time of approximately 1 second) and the water and steam can then be dumped from the modules through the dump system.
- B. The analysis report on the water/steam dump system outlining the design information for that system is found in Addendum "B".

3.5.1.8.2 OVERPRESSURE PROTECTION SYSTEM

- A. Provisions for overpressure protection of the water/steam side components have been considered and safety relief valves have been selected accordingly.
- B. The analysis report on the overpressure protection system outlining the design information for that system is found in Addendum "B".

3.5.1.9 MISCELLANEOUS SGWCS INFORMATION

Additional supplementary analyses of various other areas of design work pertaining to the overall SGWCS are found in Addendum "B".

SGWCS

Addendum "A"

Design Parameters

COMBUSTION ENGINEERING, INC.
WINDSOR, CONN.CUSTOMER AEC STEAM GENERATOR CONT. No. 2670 MADE BY — DATE —
LOCATION For LMFBR 30 MWt Model DWG. No. — CHK'D BY RCK DATE 1/26/73GENERAL NOTES FOR CIRCULATION SYSTEM
PRESSURE DROP CALCULATIONS

1. CALCULATIONS ARE PRELIMINARY AND APPROXIMATE
IN THAT THEY ARE FOR EARLY STAGE DESIGN
WORK AND HAVE NOT BEEN READJUSTED FOR
MINOR CHANGES IN HEIGHTS, LENGTHS, AND
ROUTING OF PIPING, ETC.
2. CALCULATIONS ARE BASED ON:
 - (a) 1967 ASME STEAM TABLES
 - (b) ASME BOILER AND PRESSURE VESSEL CODE,
SECTION I REQUIREMENTS
 - (c) C-E CARBON & ALLOY STEEL STOCK &
REQUISITIONING STANDARDS FOR PIPE
SIZES FOR HEADERS, LINES AND LINKS,
SI-1.2.2
 - (d) C-E FOSSIL FUEL BOILER FRICTION FACTORS,
COEFFICIENTS, FLUID VELOCITIES, ETC.
3. CALCULATIONS ARE PROVIDED FOR TWO (2)
OPERATING DESIGN POINTS; $CR=3.5$ & $CR=4.0$
THE PUMP DESIGN POINT HOWEVER WAS SELECTED
FOR THE $CR=4.0$ DESIGN CONDITIONS AS
SUMMARIZED.

CONTINUED CIRCULATION BOILER

PURCHASER AEC STEAM GENERATORMODEL LMFBR-30mw Model DWG. NO.

COMBUSTION ENGINEERING, INC.

CONTRACT NO. 7670DATE 2/1/73 BY RCK

CIRCULATING PUMP PERFORMANCE & NPSH

A. Evaporation, lb/hr 133,000 F. Drum operating press, psig 2700
 B. Pump head, psi 71 (260 FL.) G. Sat. temp. in drum, deg F 680.3
 C. Pump efficiency, pct 80 Assume H. Enthalpy, sat. water, btu/lb 759.3
 D. Motor efficiency, pct 80 Assume I. Temp., feedwtr. to drum, deg F 460
 E. Number of pumps operating 1 of 1 J. Enthalpy, feedwater, btu/lb 442

ITEM	UNITS	CALCULATING STEP	NORMAL OPERATION	MAXIMUM DESIGN
1. Drum pressure	psig		2700	2840 *
2. Circulation Ratio, CR			4.0	
3. Total circulation	lb/hr	CR x Item A	532,000	
4. Circulation per pump	lb/hr	Item 3 ÷ Item E	532,000	SA T U R A T E D
5. Heat in (CR-1) lb sat. water	btu	(CR-1) x Item H	2277	W A T E R
6. Heat in CR lb mixed water	btu	Item 5 + Item J	2719	
7. Enthalpy mixed water	btu/lb	Item 6 ÷ CR	680	
8. Mixed water temperature	deg F		645	688
9. Mixed water specific volume	cu ft/lb	(DV-94-0)	.0254	.03205
10. Volume flow per pump	cfs	Item 4 x <u>Item 9 (Norm. Oper.)</u> 3600	3.76	
11. Volume flow per pump	gpm	449 x Item 10	1700	
12. Feet mixed water per psi	ft/psi	144 x Item 9	3.66	4.61
13. Elevation, pump to drum level	ft		59	59
14. Elevation head	psi	Item 13 ÷ Item 12	16.1	12.8
15. Diam. at pump suction	in.		6.813	6.813
16. Flow area at pump suction	sq ft		0.2532	0.2532
17. Velocity at pump suction	fps	Item 10 ÷ Item 16	14.85	14.85
18. Velocity head at pump suction	psi	(Item 17) ² ÷ (Item 12 x 64.4)	0.94	0.75
19. Static suction head	psi	Item 14 - Item 18	15.2	12.0
20. Losses, drum to pump	psi		2.6	2.1
21. Static head - losses	psi	Item 19 - Item 20	12.6	9.9
22. Pump suction pressure	psig	Item 1 + Item 21	2713	2850
23. Sat. temp. at suction press.	deg F		681.1	688.4
24. Sat. press. at mixed water temp.	psig		2119	2840 *
25. Available NPSH	psi	Items (1-24 + 14-20)	594.5	10.7
26. Available NPSH	ft	Items 25 x Item 12	2125	49.3
27. Mixed water specific gravity		0.016 ⁷² Item 9	0.633	
28. Water horsepower, normal oper.	hp	Item 11 x Item B ÷ 1715	70.4	
29. Water horsepower, cold water	hp	Item 28 ÷ Item 27	111	
30. Pump brake horsepower, normal	hp	Item 28 ÷ Item C	88	
31. Pump brake horsepower, cold water	hp	Item 29 ÷ Item C	139	
32. Motor elec. power, normal oper.	kw	Item 30 ÷ (Item D x 1.341)		
33. Motor elec. power, cold water	kw	Item 31 ÷ (Item D x 1.341)		
34. Pump head at max. design press.	psi	Item B x <u>Item 9 (Norm. Oper.)</u> <u>Item 9 (Max. Design)</u>		56.4
35. Pump design pressure	psig	Items (1 + 19 + 34)		2908
36. Pump hydrostatic test press.	psig	1.5 x Item 35		4362

* Denotes
Common
Entry

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CUSTOMER AEC STEAM GENERATOR CONT. No. 7670 MADE BY — DATE —
LOCATION For LMFBR 30MWt Model DWG. No. — CHK'D BY RCK DATE 1/26/73

DOWNCOMER

Design Conditions: $P = 2875 \text{ psig}$ $T = 688^\circ\text{F}$
SA-335 P-22 $S = 15,000$

$$\text{ASME } t_m = \frac{(2875)(8.625)}{(2)(15,000) + (.8)(2875)} = 0.768''$$

$$t_{\text{AVG}} = 0.877'', \text{ Use } 0.906'' \text{ (Schedule 160)}$$

$$1 - 8\frac{5}{8}'' \text{ O.D. X Sch. 160 I.D.} = 6.813'' \quad A = 0.2532 \text{ Ft}^2$$

$$CR = 3.5$$

$$\text{Total Flow} = \frac{(465,000)(.0250)}{(3600)} = 3.23 \text{ cfs}$$

$$V_{\text{el.}} = \frac{3.23}{.2532} = 12.78 \text{ Ft/sec}$$

$$K_H = \frac{(12.78)^2}{(64.4)(144)(.0250)} = 0.703 \text{ psi}$$

$$L = 50 \text{ Ft}, K_L = \frac{(.015)(50)(12)}{(6.813)} = 1.32$$

$$K_{\text{TOTAL}}$$

$$K_L = 1.32$$

$$K_{\text{ENT}} = 1.50$$

$$+ \text{EXIT } 2.82$$

$$\Delta P = (2.82)(0.703) = 1.98 \text{ psi}$$

$$CR = 4.0$$

$$\text{Total Flow} = \frac{(532,000)(.0254)}{(3600)} = 3.76 \text{ cfs}$$

$$V_{\text{el.}} = \frac{3.76}{.2532} = 14.85 \text{ Ft/sec}$$

$$K_H = \frac{(14.85)^2}{(64.4)(144)(.0254)} = 0.936 \text{ psi}$$

$$K_{\text{TOTAL}} = 2.82$$

$$\Delta P = (2.82)(0.936) = 2.64 \text{ psi}$$

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CUSTOMER AEC STEAM GENERATOR CONT. No. 7670 MADE BY — DATE —
LOCATION For LMFBR 30 MWt Model DWG. No. — CHK'D BY RCK DATE 1/26/73

PUMP DISCHARGE (EVAPORATOR INLET) LINE

Design Conditions: $P = 2950$ psig $T = 688^\circ\text{F}$
 $SA-335 P-22$ $S = 15,000$

$$ASME \ t_m = \frac{(2950)(8.625)}{(2)(15,000) + (.8)(2950)} = 0.787"$$

$$e \ t_m / o = \frac{0.787}{8.625} = 0.0913, \text{ Corr. Factor For Bending} = 1.023$$

$$\text{corr. } t_m = (1.023)(0.787) = 0.806"$$

$$t_{\text{AVG}} = 0.922", \text{ Use } 0.9375" \left(15\frac{1}{16}"\right)$$

$$1 - 8\frac{5}{8}" \text{ O.D. } \times 15\frac{1}{16}" \text{ Avg. Thk. I.D.} = 6.75" \ A = 0.248 \text{ Ft}^2$$

$$CR = 3.5$$

$$V_{el.} = \frac{3.23}{0.248} = 13.0 \text{ Ft/sec}$$

$$K_H = \frac{(13.0)^2}{(64.4)(144)(.0250)} = 0.727 \text{ psi}$$

$$L = 22 \text{ Ft}, \ K_L = \frac{(.015)(22)(12)}{(6.75)} = .586$$

$$K_{\text{TOTAL}}$$

$$K_L = 0.586$$

$$K_{4 \times 90^\circ} = 1.36$$

$$K_{\text{EXIT}} = \frac{1.00}{2.946}$$

$$\Delta P = (2.946)(.727) = 2.14 \text{ psi}$$

$$CR = 4.0$$

$$V_{el.} = \frac{3.76}{0.248} = 15.15 \text{ Ft/sec}$$

$$K_H = \frac{(15.15)^2}{(64.4)(144)(.0254)} = 0.974 \text{ psi}$$

$$K_{\text{TOTAL}} = 2.946$$

$$\Delta P = (2.946)(0.974) = 2.86 \text{ psi}$$

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CUSTOMER AEC STEAM GENERATOR CONT. No. 7670 MADE BY — DATE —
LOCATION For LMFR 30 MWt Model DWG. No. — CHK'D BY RCK DATE 1/26/73

EVAPORATOR (STEAM/WATER MIXTURE) OUTLET

Design Conditions: 2900 Psig $T = 688^\circ\text{F}$
SA-335 P-22 $S = 15,000$

$$\text{ASME } t_m = \frac{(2900)(8.625)}{(2)(15,000) + (.8)(2900)} = 0.775"$$

$$@ t_m/D = \frac{0.775}{8.625} = 0.090, \text{ Corr. Factor For Bending} = 1.026$$

$$\text{Corr. } t_m = (1.026)(0.775) = 0.795"$$

$$t_{\text{AVE}} = 0.908", \text{ Use } 0.9375" (15/16")$$

$$1 - 8\frac{5}{8}" \text{ O.D. } \times 15/16" \text{ Avg. Thk. I.D.} = 6.75" A = 0.248 \text{ Ft}^2$$

$$CR = 3.5$$

$$\text{Total Flow} = \frac{(465,500)(.0534)}{(3600)} = 6.9 \text{ cfs}$$

$$V_{\text{el.}} = \frac{6.9}{.248} = 27.8 \text{ Ft/sec}$$

$$K_H = \frac{(27.8)^2}{(64.4)(144)(.0534)} = 1.562 \text{ psi}$$

$$L = 70 \text{ Ft}, K_L = 1.86$$

$$K_{\text{TOTAL}}$$

$$K_L = 1.86 + K_A = 1.36 + K_{\text{ENT}} = 0.50$$

$$K_{\text{TOTAL}} = 3.72$$

$$\Delta P = (3.72)(1.562) = 5.81 \text{ psi}$$

$$CR = 4.0$$

$$\text{Total Flow} = \frac{(532,000)(.0505)}{(3600)} = 7.46 \text{ cfs}$$

$$V_{\text{el.}} = \frac{7.46}{.248} = 30.1 \text{ Ft/sec}$$

$$K_H = \frac{(30.1)^2}{(64.4)(144)(.0505)} = 1.935 \text{ psi}$$

$$K_{\text{TOTAL}} = 3.72$$

$$\Delta P = (3.72)(1.935) = 7.2 \text{ psi}$$

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CUSTOMER AEC STEAM GENERATOR CONT. NO. 7670 MADE BY --- DATE ---
LOCATION For LMFBR 30MWt Model DWG. NO. --- CHK'D BY RCK DATE 1/26/73

EVAPORATOR OUTLET DISTR. HEADER

Design conditions: $P = 2900$ Psig $T = 688^{\circ}\text{F}$

SA-387 D Normalized & Tempered

$$S = 17,100$$

$$\text{ASME } t_m = \frac{(2900)(12.75)}{(2)(17,100) + (.8)(2900)} = 1.013''$$

$$\text{Use } t_m = 1.062'' \quad \text{I.D.} = 10.50'' \quad A = 0.601 \text{ Ft}^2$$

$$CR = 3.5$$

$$V_{el.} = \frac{6.9}{.601} = 11.47 \text{ Ft/sec}$$

$$K_H = \frac{(11.47)^2}{(64.4)(144)(.0534)} = 0.266 \text{ psi}$$

DP = Negligible

$$CR = 4.0$$

$$V_{el.} = \frac{7.46}{.601} = 12.42 \text{ Ft/sec}$$

$$K_H = \frac{(12.42)^2}{(64.4)(144)(.0505)} = 0.33 \text{ psi}$$

DP = Negligible

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CUSTOMER AEC STEAM GENERATOR CONT. No. 7670 MADE BY — DATE —
LOCATION For LMFBR 30 MWt Model DWG. No. — CHK'D BY RCK DATE 1/26/73

Relief Tubes - 5" O.D.

Design Conditions: $P = 2840$ psig $T = 688^\circ F$

SA-213 T-22

$S = 15,000$

$$Y = \frac{P}{S} = \frac{2840}{15,000} = 0.189, \text{ Use } 0.480 \text{ MWt } Y = 0.200$$

6-5" O.D. X 0.480 MWt I.D. = 3.915" $A = 0.0836 \text{ Ft}^2$

$$CR = 3.5$$

$$V_{el.} = \frac{6.9}{(6)(0.0836)} = 13.75 \text{ Ft/sec}$$

$$K_H = \frac{(13.75)^2}{(64.4)(144)(0.0534)} = 0.382 \text{ psi}$$

$$L = 20 \text{ Ft}$$

$$K_L = \frac{(0.024)(20)(12)}{(3.915)} = 1.47$$

$$K_A = 0.84$$

$$K_{ENT+EXIT} = \frac{(1.5)\left(\frac{3.915}{3.50}\right)^4}{*} = \frac{2.34}{4.65}$$

$$DP = (4.65)(0.382) = 1.78 \text{ psi}$$

* Nozzle I.D. = 3.50"

$$CR = 4.0$$

$$V_{el.} = \frac{7.46}{(6)(0.0836)} = 14.9 \text{ Ft/sec}$$

$$K_H = \frac{(14.9)^2}{(64.4)(144)(0.0505)} = 0.474 \text{ psi}$$

$$K_{TOTAL} = 4.65$$

$$DP = (4.65)(0.474) = 2.2 \text{ psi}$$

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CUSTOMER AEC STEAM GENERATOR CONT. No. 7670 MADE BY — DATE —
LOCATION For LMFBF 30mw± Model DWG. No. — CHK'D BY RCK DATE 1/26/73

Net Hydro Head

* No Credit Will Be Taken For
Evaporator NHH Helping
Circulation.

$$CR = 3.5$$

$$COLD\ LEG = \frac{(52)}{(144)(.0250)} = 14.4\ psi$$

$$HOT\ LEG = \frac{(52)}{(144)(.0534)} = 6.8\ psi$$

$$NHH = 7.6\ psi$$

$$CR = 4.0$$

$$COLD\ LEG = \frac{(52)}{(144)(.0254)} = 14.2\ psi$$

$$HOT\ LEG = \frac{(52)}{(144)(.0505)} = 7.2\ psi$$

$$NHH = 7.0\ psi$$

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CUSTOMER AEC STEAM GENERATOR CONT. No. 7670 MADE BY — DATE —
LOCATION For LMFR 30MWt Model DWG. No. — CHK'D BY RCK DATE 1/26/73

WATER
 ΔP SUMMARY RECIRCULATION SYSTEM (PSI)

	<u>CR=3.5</u>	<u>Pump Design Point</u> <u>CR=4.0</u>
ΔP , DRUM TO PUMP	1.98	2.64
ΔP , PUMP DISCHARGE LINE	2.14	2.86
ΔP , FULL OPEN CONTROL VALVE & FLOWMETER	**	9.00
ΔP , EVAP. INLET ISOL. VALVE	2.00	2.70
ΔP , EVAPORATOR ORIFICE	*	20.00
ΔP , EVAPORATOR	21.00	27.40
ΔP , EVAP. OUTLET ISOL. VALVE	2.00	2.48
ΔP , EVAPORATOR OUTLET LINE	5.81	7.20
ΔP , RELIEF TUBES	1.78	2.20
ΔP , DRUM INTERNALS	1.00	1.00
TOTAL		77.48
NH H		7.00
NET PUMP HEAD		70.48
USE		71.00

* The pump system will have the flexibility of providing some orifice ΔP at the evaporator inlet.

** The control valve (sized for approx. 5-6 psi at the full open position at the CR=4.0 condition) will be throttled down to the necessary ΔP (governed by the amount of desired evaporator orifice ΔP and available Pump Head at the CR=3.5 flow conditions).

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CUSTOMER REC STEAM GENERATOR CONT. No. 7670 MADE BY — DATE —
LOCATION For LMFBR 30 MWT Model DWG. No. — CHK'D BY RCK DATE 1/26/73

APPROX. WATER RECIRCULATION SYSTEM PRESSURES

	<u>OPERATING, PSIG</u>	<u>DESIGN PRESS. & TEMP.</u>
DRUM	2700	2840 + 688
PUMP SUCTION	2713	2850 + 688
PUMP DISCHARGE	2784	2900 + 688
EVAPORATOR INLET NOZZ.	2767	2900 + 688
EVAPORATOR OUTLET NOZZ.	2720	2900 + 688
EVAP. OUTLET DIST. HDR.	2703	2840 + 688
DRUM	2700	2840 + 688

COMBUSTION ENGINEERING, INC.

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CUSTOMER AEC STEAM GENERATOR CONT. No. 7670 MADE BY — DATE —
 LOCATION For LMFBR 30 MWT Model DWG. No. — CHK'D BY RCK DATE 1/26/73

SATURATED STEAM CONNECTING TUBES — 3½" O.D.

Design Conditions: $P = 2840$ psig $T = 688^\circ\text{F}$
 SA-213 T-2a

$$Y = \frac{P}{S} = \frac{2840}{15,000} = 0.189, \text{ USE } 0.340 \text{ MWT } Y = 0.203$$

3-3½" O.D. X 0.340 MWT I.D. = 2.732" $A = .0407 \text{ Ft}^2$

Flow = 133,000 #/hr SAT. STEAM @ 688°F & 2700 Psig

$$\text{Flow} = \frac{(133,000)(0.11063)}{(3600)} = 4.08 \text{ cfs}$$

$$V_{cl} = \frac{4.08}{(3)(.0407)} = 33.4 \text{ Ft/sec.}$$

$$\Delta P = \frac{(4.11)(F)^{1.85} (T.E.L.) (\nu)}{(10,000)(ID)^{4.97}}$$

$F = \text{\#}/\text{min} / \text{tube}$, T.E.L. = Total Equivalent Length of Pipe

$\nu = \text{specific volume}$ ID = Inside Diameter of Tube

$$\Delta P = \frac{(4.11)(740)^{1.85} (40)(.11063)}{(10,000)(2.732)^{4.97}} = 2.51 \text{ psi}$$

COMBUSTION ENGINEERING, INC.

WINDSOR, CONN.

CUSTOMER REC STEAM GENERATOR CONT. No. 7670 MADE BY — DATE —
 LOCATION For LMFBR 30 MWt Model DWG. No. — CHK'D BY RCK DATE 1/26/73

SATURATED STEAM COLLECTING HEADER

Design Conditions: $P = 2840$ psig $T = 688^\circ F$

SA-335 P-22

$S = 15,000$

$$\text{ASME } t_m = \frac{(10.75)(2840)}{(2)(15,000) + (0.8)(2840)} = 0.945''$$

$t_{\text{AVE.}} = 1.08''$, Use $1.125''$ ($1\frac{1}{8}''$) Schedule 160

1- $10\frac{3}{4}''$ O.D. X Sch. 160 I.D. = $8.50''$ $A = 0.3945 \text{ Ft}^2$

$$X = \frac{4.08}{0.3945} = 10.35 \text{ Ft/sec}$$

$$X_H = \frac{(10.35)^2}{(64.4)(144)(.11063)} = 0.105 \text{ psi}$$

$DP = \text{Negligible}$

COMBUSTION ENGINEERING, INC.
WINDSOR, CONN.

CUSTOMER AEC STEAM GENERATOR CONT. No. 7670 MADE BY — DATE —
LOCATION For LMFBR 30 MWt Model DWG. No. — CHK'D BY RCK DATE 1/26/73

SUPERHEATER INLET LINE

Design Conditions: $P = 2840$ psig $T = 688^\circ F$

SA-335 P-22

$S = 15,000$

$$\text{ASME } t_m = \frac{(2840)(6.625)}{(2)(15,000) + (.8)(2840)} = 0.582''$$

$$@ t_m/D = \frac{0.582}{6.625} = 0.088, \text{ Corr. Factor For Bending} = 1.03$$

$$\text{corr. } t_m = (1.03)(0.582) = 0.600''$$

$$t_{\text{AVG.}} = 0.686'', \text{ Use } 0.6875'' \text{ (} 11/16 \text{ '')}$$

$$DP = \left(\frac{1.306}{10^4} \right) \left(1 + \frac{3.6}{ID} \right) (F)^2 (\nu) \left(\frac{T.E.L.}{ID^5} \right)$$

$F = \#/\text{min}/\text{LINE}$ $\nu = \text{specific volume}$

T.E.L. = Total Equivalent Length of Pipe

ID = Inside Diameter of Pipe

$$1-6\frac{5}{8}'' \text{ O.D. } \times \frac{11}{16}'' \text{ Avg. Thk. } I.D. = 5.25'' \quad A = 0.150 \text{ Ft}^2$$

$$DP = \left(\frac{1.306}{10^4} \right) \left(1 + \frac{3.6}{5.25} \right) (2216)^2 (.11063) \left(\frac{127}{5.25^5} \right)$$

$$DP = 3.8 \text{ psi}$$

COMBUSTION ENGINEERING, INC.
WINDSOR, CONN.

CUSTOMER AEC STEAM GENERATOR CONT. No. 7670 MADE BY — DATE —
LOCATION For LMFBR 30mw Model DWG. No. — CHK'D BY RCK DATE 1/26/73

SUPERHEATER OUTLET LINE

Design Conditions: $P = 2840 \text{ psig}$ $T = 960^\circ \text{ F}$

SA-335 P-22

$S = 10,350$

$$\text{ASME } t_m = \frac{(2840)(8.625)}{(2)(10,350) + (.8)(2840)} = 1.062''$$

$$@ t_m/D = \frac{1.062}{8.625} = 0.123, \text{ Corr. Factor For Bending} = 1.0$$

$$\text{Corr. } t_m = (1.0)(1.062) = 1.062''$$

$$t_{\text{avg.}} = 1.215'', \text{ Use } 1.25'' (1\frac{1}{4}'')$$

$$1 - 8\frac{5}{8}'' \text{ O.D. } \times 1\frac{1}{4}'' \text{ Avg. Thk. I.D.} = 6.125'' A = .2045 \text{ Ft}^2$$

$$@ 900^\circ \text{ F } \& \sim 2590 \text{ psig } v = 0.2585 \text{ Ft}^3/\text{lb}$$

$$V_{el.} = \frac{(133,000)(.2585)}{(3600)(.2045)} = 46.6 \text{ Ft/sec}$$

COMBUSTION ENGINEERING, INC.
WINDSOR, CONN.

CUSTOMER REC STEAM GENERATOR CONT. No. 7670 MADE BY — DATE —
LOCATION For LMFBR 30 MWt Model DWG. No. — CHK'D BY RCK DATE 1/26/73

DP STEAM SIDE PIPING SYSTEM (PSI)

DP, SAT. STEAM CONNECTING TUBES	2.51
DP, SUPERHEATER INLET LINE	3.80
DP, SUPHTR. INLET ISOLATION VALVE	5.00
DP, SUPERHEATER	100.00
DP, SUPHTR. OUTLET ISOLATION VALVE	<u>30.00</u>

TOTAL, DRUM TO SUPHTR. OUTLET ISOL. VALVE.	141.31
---	--------

TOTAL, DRUM TO SUPHTR.	141.31
OUTLET NOZZLE CONN.	<u>-30.00</u>
	111.31

APPROX. SUPERHEATER STEAM SIDE PRESSURES

	<u>OPERATING, PSIG</u>	<u>DESIGN PRESS. & TEMP.</u>
DRUM	2700	2840 + 688
SAT. STEAM COLL. HEADER	2697	2840 + 688
SUPHTR. INLET NOZZLE CONN.	2688	2840 + 688
SUPHTR. OUTLET NOZZLE CONN.	2588	2840 + 960
SUPHTR. OUTLET <u>C-E</u> CONN. <u>SCTI</u>	2558	2840 + 960

Combustion Engineering, Inc.

ENGINEERING DEPT.

WINDSOR, CONN.

CE 2506 (2-59)

BOILER CIRCULATION SYSTEM

SHEET 16 OF 17

Contract No. 7670 Name LMFBF - 30 MWT Model

PRELIMINARY ONLY

HEADERS, PIPING AND MISC. DATA

Quantities indicated are per boiler.

PRELIMINARY ONLY

	ITEM	NO. REQ'D.	O. D. INS.	I. D. OR THICK - INS.	A. S. M. E. SPEC.	DESIGN		NIPPLE DESIGN TEMP. °F	CONNECTIONS
						PRESS. PSIG	TEMP. °F		
1	Feedwater Line to Steam Drum	1	6 5/8		SA-				
2	Steam Drum	1	-	60 ID	SA-387 D	2840	688		6'-6" ϕ to ϕ welds
3	Downcomer	1	8 5/8	Sch. 160	SA-335 P-22	2875	688		
4	Circulating Pump	1			SA-	2900	688		Inverted. Single Discharge
5	Pump Discharge Line	1	8 5/8	15/16 Avg	SA-335 P-22	2900	688		
6	Evaporator Outlet Line	1	8 5/8	15/16 Avg	SA-335 P-22	2900	688		
7	Evaporator Outlet Distr. Header	1	12 3/4	10.50	SA-387 D	2900	688		1-8 5/8" @ end 6-5"
8	Relief Tubes	6	5	.480 MWT	SA-213 T-22	2840	688		
9	Saturated Steam Conn. Tubes	3	3 1/2	.340 MWT	SA-213 T-22	2840	688		
10	Saturated Steam Collect. Header	1	10 3/4	Sch. 160	SA-335 P-22	2840	688		3-3 1/2" 1-6 5/8" @ end
11	Superheater Inlet Line	1	6 5/8	11/16 Avg	SA-335 P-22	2840	688		
12	Superheater Outlet Line	1	8 5/8	1 1/4 Avg	SA-335 P-22	2840	960		
E1	Evap. Inlet Quick Closing Valve	1			SA-	2900	688		
E2	Evap. Outlet Quick Closing Valve	1			SA-	2900	688		
S1	Superheater Inlet Quick Closing Valve	1			SA-	2840	688		
S2	Superheater Outlet Quick Closing Valve	1			SA-	2840	960		

Steam Drum to have 2 rows of 8 1/2" dia. Turbo Separators, using 3 per row. The 8 1/2" dia. Turbo Separators in each row are to be on 18 1/2" centers.

Remarks SA-387 D plate for the 60" ID steam drum and the 12 3/4" O.D. Evaporator Outlet

Distr. Header is to be normalized and tempered.

LMFBR - 30 MW± Model - Contract No. 7670WATER RECIRCULATION SYSTEM

—— Water/Steam Piping (Water Recirculation System)
 ---- Secondary Sodium Piping

3.5.2 CONTROLS

3.5.2.1 GENERAL

The control system arrangement for the C-E 30 MWt test model steam generator is based on the same philosophy and control system design strategy which has been described in the SDD for the C-E LMFBR demo plant. The demo plant SDD was entitled "System Design Description for Steam Generator Instrumentation and Control System (SDD-SGICS)." All work reported herein for the 30 MWt control system is referenced to this SDD, which must be read to have a complete understanding of the test model control system.

The 30 MWt test model steam generator is to be installed in the existing Sodium Components Test Installation (SCTI) located at the Liquid Metal Engineering Center (LMEC). Therefore, the steam generator control system must be integrated and interfaced with existing control system equipment at SCTI. Based on both our review of the SDD for the existing SCTI control system equipment and our orientation visit to SCTI, we decided that the best method of approach was to design the control system from the functional standpoint without planning to use any particular item of the existing control equipment at SCTI, with one major exception. That exception was the actuator elements and the final control elements. These existing elements are pneumatic devices. It is normal C-E practice to recommend the use of electronic control system equipment and electric actuators. Therefore, we decided

3.5.2.1 (continued)

to plan on using electronic controllers and equipment down to the existing pneumatic actuators at SCTI. At this point, the interface could be made with commercially available electric pneumatic converters. With this approach, our own control system design could most easily and efficiently be provided in separate relay racks, with a minimum of interfacing to the existing SCTI equipment.

Any final control system arrangement must be coordinated with and approved by LMEC, especially in regard to safety systems and operating procedures. Naturally, if any existing SCTI control equipment could conveniently be adapted into our system design, it would be desirable to do so. For example, the existing primary and secondary sodium flow rate meters should be used in our control system. A complete determination of which existing particular equipment items can be arrived at only after a review of our control system design and objectives by LMEC. It is believed that the approach we have taken would enable this coordinated effort to proceed with the least amount of rearrangement of the existing equipment and to accomplish the C-E control system objectives with the least cost in modification of the existing SCTI equipment.

3.5.2.2 CONTROL SYSTEM DESCRIPTION

The control system design description is contained mainly in a set of nine (9) drawings. These drawing numbers are indexed as follows:

3.5.2.2 (continued)

<u>Drawing No.</u>	<u>Figure No.</u>
07670-ID4600-00	Figure 1 of 9
" ID4601-00	" 2 of 9
" ID4602-00	" 3 of 9
" ID4603-00	" 4 of 9
" ID4604-00	" 5 of 9
" ID4605-00	" 6 of 9
" ID4606-00	" 7 of 9
" ID4607-00	" 8 of 9
" ID4608-00	" 9 of 9

This set of nine (9) figures has been given the same title as follows:

"Control System Arrangement and
Functional Schematic
LMFBR Steam Generator
30 MWt Model"

3.5.2.3 FUNCTIONAL SCHEMATIC LEGEND

Figure 1 contains a list and definition of symbols, which are used in the Functional Schematics (Figures 6 to 9).

3.5.2.4 STEAM GENERATION SCHEMATIC FLOW DIAGRAM

Figure 2 provides a schematic of the sodium heated test model steam generator and identifies principal measured variables.

3.5.2.5 FEEDBACK CONTROL ARRANGEMENTS FOR SUPERHEATED STEAM TEMPERATURE AND "THROTTLE" PRESSURE CONTROL

Figure 3 was copied after a similar drawing included in the referenced SDD for the demo plant. Its purpose is to show how

3.5.2.5 (continued)

a non-interactive control system strategy has been applied to controlling superheated steam temperature and steam pressure (control strategies B + C). A complete description of this non-interactive principal is contained in the referenced SDD for the demo plant.

3.5.2.6 PLANT COORDINATED CONTROL SYSTEM BASE LOAD MODE CONFIGURATION

Figure 4 shows the complete test model control system configuration for the Base Load Mode (BLM) of operation. BLM is one of two automatic modes of operation, which is described in the referenced SDD for the demo plant. For the test model, the coordinating assembly produces a plant required output (PRO), which will be a steam generator output in steam flow rate, rather than electrical megawatts as in the demo plant.

3.5.2.7 PLANT COORDINATED CONTROL SYSTEM COORDINATED MODE CONFIGURATION

Figure 5 contains the Coordinated Mode (CM) configuration for the test model. This is the principal automatic mode of operation, which includes the non-interactive control system for steam pressure and steam temperature, which is shown in Figure 3. As in the BLM, the CM for the test model establishes a desired steam flow for the plant required output (PRO).

3.5.2.8 FUNCTIONAL SCHEMATICS - SUBSYSTEM CONTROLS

Figures 6 through 9 are functional schematics for the SCTI/ test model steam generator control system. These functional drawings would provide the basis for a detailed control system design. The schematics implement the total plant control system concept, which is shown in the BLM and CM configurations, Figures 4 and 5. The subsystem schematic drawings are identified as follows:

3.5.2.8 (continued)

Figure 6 Fuel and Air Control Subsystem

Figure 7 Primary and Secondary Sodium Flow Rate Control Subsystem

Figure 8 Feedwater Flow Control Subsystem

Figure 9 Steam Reducing Valve Control Subsystem

The basic control system design strategy is embodied in the above four figures. As emphasized throughout this write-up, a complete understanding of the control system philosophy and design can be obtained only by reading the referenced SDD (SDD-SGICS) for the C-E LMFBR demo plant. A more complete written description for the test model steam generation was not possible because of the unanticipated early cut-off date of the test model contract.

SGWCS

Addendum "B"

SUPPLEMENTARY ANALYSES AND REPORTS

1. Water/Steam Isolation and Dump System.
2. Overpressure Protection System - Relief Valves and Silencers.
3. 60 " I.D. Steam Drum Analyses.
4. Preliminary Piping Flexibility.
5. Structural Steel Analyses.

SGWCS

Addendum "C"

DRAWINGS

<u>Drawing No.</u>	<u>Drawing Title</u>
1. 07670-1E0314	Steam Generator Flow Diagram
2. 07670-1F0109	Arrgt. of Pressure Parts - Sectional Side Elevation
3. 07670-1F0119	Arrgt. of Pressure Parts - Front Elev. View "E-E"
4. 07670-1E0131	Arrgt. of Pressure Parts - Plan Views "A-A" & "B-B"
5. 07670-1E0132	Arrgt. of Pressure Parts - Plan Views "C-C" & "D-D"
6. 07670-1E0303	General Arrgt. - Side Elevation Looking North
7. 07670-1E0305	General Arrgt. - Front Elevation Looking West
8. 07670-1E0400	Flow Diagram Steam Gen. Water Circulation Pump
9. 07670-1E1402	Detail Assembly of 60" I.D. Steam Drum
10. 07670-1E1407	Arrgt. of Internals for 60" I.D. Steam Drum
11. 07670-1E1408	Detail of Internal Head Panel Plate
12. 07670-1B1457	Material for 60" I.D. Steam Drum
13. 07670-1B1458	16" O.D. Manhole Cover
14. 07670-1C1446	Detail of 8" Downcomer Nozzle
15. 07670-1C6950	Column Lines "I" & "3"
16. 07670-1C6951	Miscellaneous Platforms and Stairs
17. 07670-1C6952	Column Lines "H" & "5"
18. 07670-1C6953	Miscellaneous Platforms and Stairs
19. 07670-1C6954	Superheater and Evaporator Supports
20. 07670-1C6955	Column Lines "5A" & "3A"
21. 07670-1C6956	Base Plates and Column Loads

3.6 Maintenance

3.6.1 Introduction

The design of a steam generator for an LMFBR plant should provide the greatest possible access, ease and versatility for in-service inspection and maintenance. Two of the inherent advantages of any bayonet tube design are that the pressure tubes are of a relatively large diameter and require only one tubesheet. This tubesheet is located at the top end of the unit which further simplifies maintenance and inspection.

The bayonet tube steam generator design in this report provides excellent access to perform any maintenance and inspection tasks that could be required. No sophisticated remote tooling will be required for any of the maintenance tasks unless it becomes necessary to repair a tube leak or to replace a faulted tube. These operations would of course require internal bore cutting and welding equipment to provide a crevice free welded joint similar to the original shop welded joint.

The steam generator consists of one evaporator module and one superheater module. The tube bundles are contained in separate shells and are connected by a steam drum and circulation piping. The design concept is the same for the evaporator and superheater modules and the difference between the modules is in the physical size, number of tubes, shell and head thicknesses, etc. The bulk of these discussions is directed toward the major inspection and maintenance tasks that will require partial disassembly of the unit. Not discussed are those items such as instrumentation, control, etc., that will require periodic maintenance and inspection.

3. 6. 2 Disassembly

The following sketch illustrates the design of the bayonet tube module.

Maintenance and repair procedures will be the same for either the superheater or evaporator module.

3. 6. 2 Continued

The module can be disassembled as shown in the following illustrations. It is assumed that all insulation has been removed where necessary.

Top Head Removal - Top head removal

will consist simply of unbolting and lifting the head from the unit. The seal at this joint consists of dual, self-energizing metal "O" rings. Seal weld cutting will not be required.

The top head contains no nozzles and thus no piping disconnections will be necessary.

Removal of the top head exposes the internals within the upper channel.

These internals are the inlet (super-heater outlet) plenum to which the bayonet tubes are attached, and the

plenum cover. This cover is bolted to a flange at the top of the plenum cylinder.

A flow distribution pipe is attached to the plenum cover plate. The plenum is secured within the channel by bolting to lugs on the channel shell.

The plenum cover may be removed by removing the bolts and lifting from the unit.

3. 6. 2 Continued

At this point in disassembly, the double walled bayonet tubes may be removed individually by removing the threaded fittings that secure the flared ends of the tubes to the plenum tubesheet and lifting the tubes from the unit. The plenum may now be removed by unbolting and lifting from the unit.

It might be possible to remove the entire assembly by unbolting the plenum and lifting from the unit as shown here. Whether this will be possible must await actual testing of the component. Functional loads of the bayonet tubes within the high pressure heat transfer tubes are difficult to predict, particularly after a period of operation.

After the bayonet tubes and plenum are removed, the high pressure tubesheet and channel are completely exposed for maintenance and/or inspection.

3. 6. 2 Continued

Removal of the tube bundle from the sodium shell is accomplished in the following manner. The studs securing the tubesheet flange to the sodium shell will be removed. Stud tensioners will not be required for removal of the nuts.

This provides full circle access to the seal welded membrane. No gaskets are used at this joint. The seal weld will then be cut completely around the flanges. An automatic weld cutting machine will probably be utilized to machine through the seal weld. Circular tracks for this equipment can be mounted on the vessel flange. This weld can also be cut manually. Chip dams will be provided to prevent chips from entering the vessel.

3.6.2 Continued

While the seal weld is being cut, the circulation piping will be disconnected. Two water/steam lines are attached to the nozzles in the channels. These pipes will contain flanged connections to simplify this task. Once the seal weld is cut and the piping disconnected, the tube bundle can be lifted from the sodium shell.

A lifting fixture will be bolted to the flanges at the top end of the unit. A vertical lift of approximately 38-40 feet will clear the tube bundle for horizontal movement.

3.6.3 Inservice Inspection

Inservice inspection of the steam generator will be required periodically. This intent of this inspection is to maintain the highest degree of safety and reliability possible. ASME Code Section XI "Rules for Inservice Inspection of Nuclear Reactor Coolant Systems" delineates the requirements and scope for these periodic inspections. Those areas most predominantly selected for examination are the welds and adjacent metal in the pressure containing boundary. These and other areas that are suspect, such as discontinuities and areas of high thermal or mechanical stresses will be examined by selected non-destructive procedures. Examples of these include the shell girth and long seam weld joints, nozzle attachments, tube-to-tubesheet joints etc. The most critical of these pressure boundaries in a sodium heated steam generator is the pressure boundary between the water and sodium. This boundary is the high pressure heat transfer tubes and the tubesheet to which they are attached. All welds in the shells and at nozzles can be exposed by removal of the insulation and heaters from the components. The insulation of these steam generators consists of all metal reflective foil assemblies that buckle together to enclose the vessel and nozzles. Electrical strip heaters will be an integral part of these insulation subassemblies. Inspection of the sodium water pressure boundary will require partial disassembly as discussed previously to provide access to the high pressure tubesheet. Examination here will be spot checking of heat transfer tubing and tubesheet. The inner surfaces of all tubes can be 100% inspected visually by boroscopic techniques and volumetrically by ultrasonic and eddy current equipment. Fluorescent dye penetrant inspection can also be used for I.D. inspection to the heat transfer tubing.

3. 6. 4 Maintenance - Methods and Procedures

The objective of this discussion is to present the proposed procedures and alternatives that are available for the plugging, repair or replacement of the tubing within the bayonet tube, sodium heated steam generator. These procedures are based upon failure of the heat transfer tubing after power operation of the subject steam generator. The major topics of discussion are the leak location, plugging, repair or replacement and testing of the high pressure sodium/water boundary heat transfer tubes in the steam generator. It is assumed that a tube leak resulting in a sodium water reaction is detected and that the normal steam generator isolation and normal shutdown has been accomplished.

3. 6. 4. 1

Leak Location - The first task in the repair procedure will be to locate and pin point the tube leak. Leak location for this design concept can be accomplished in a number of ways. Some of these methods are listed along with some of the advantages and/or disadvantages of that particular method.

1. Helium Mass Spectrometer - Pressurize sodium shell with helium and survey tubesheet surface with helium sniffers. This is a proven method that has been used previously but often proves very difficult. The diffusivity of helium into air is rapid and unless the air at the surface is continually replaced, the probe will indicate helium several feet from the actual source. With proper precautions, however, this method will locate a leak. Gas pressure is limited.
2. Bubble - Fill tubes with water or other fluid to surface of tubesheet, pressurize sodium shell and observe for bubbles at leaky tube. This method has the dis-

3.6.4.1 Continued

advantage of filling the tubes with water or other fluids that must be pumped out later. Water should not be used because of leakage into the shell. Gas pressure is limited.

3. Acoustic Detection - Pressurize shell and use acoustic equipment to listen for gas passage through the leak. This method might prove to be the simplest and most dependable if sufficiently sensitive equipment is available. Gas pressure is limited.
4. Stoppers - Some form of stoppers are inserted into the tube holes in the tube-sheet and the shell side pressurized. Gas leakage into the tube will force the stopper out. Shell side gas pressure is limited and the leak tightness of the stoppers or plugs must be assured.
5. Tube Pressurization - Insert some form of stopper or plug into the tube hole in the tubesheet and pressurize the tube through the plug. Observe gas pressure for leakage into the shell. This method has the distinct advantage that high pressures can be used if the leak is extremely small or has been self-plugged. Equipment requirements are minimal and shell pressurization is not required.

Of the above outlined procedures for leak location, the last one, tube pressurization, is recommended for initial efforts in locating the leak. Once the leaking tube has been located, a decision must be made whether to plug the tube at this point or to pinpoint the leak and determine the extent of damage. It is recommended that further investigations be performed to determine if adjacent tubes have been damaged by wastage caused by impingement from the leaking tube. Assuming a decision is made to investigate further, the next task will be to pinpoint just where the leak is within the tube. The inside surfaces of the tube can be examined visually using boroscopic equipment. If this fails to locate the leak, a mechanism can be designed to pressure

3. 6. 4. 1 Continued

test the tube in stages as illustrated in this sketch. The space between the seals is pressurized. As the pressurized segment is traversed by the leak, pressure is lost.

Once this is accomplished, a detailed investigation of the area will be initiated to determine the extent of damage.

Volumetric examination of the tube defect can be accomplished by eddy current, ultrasonic and radiographic techniques. These forms of inspection are within the present state of the art for a straight tube with a relatively large I. D. (approximately 1-1/8 inch) although some development work and equipment design will undoubtedly be required.

3. 6. 4. 2

In Place Repair of High Pressure Heat Transfer Tubes - Whether or not it will be possible to repair a tube will depend on the severity, type and location of the defect. First of all the failure would have had to occur within approximately 2-6 inches of the tubesheet face dependent upon equipment limitations. Secondly, the failure would have to be of the type amenable to repair welding such as a localized pin hole or a circumferential defect. The type and extent of defect can be determined by exploratory machining and nondestructive testing such as liquid penetrant inspection. After the decision is made to repair a tube, the following steps will be performed:
(Refer to Figure 3. 6-1)

Figure 3.6-1

- Step 1 - Examine for location of remaining defect.
- Step 2 - GTA first pass to fuse remainder of the defect.
- Step 3 - Complete weld using filler wire and multiple passes.
- Step 4 - Post heat treatment.
- Step 5 - Perform NDT.
- Step 6 - Hydrotest---a single tube may be hydrotested without
pressurizing the entire steam/water side.

3.6.4.3

Renewal of High Pressure Tubes - If a failure occurs in a tube at any other location more than approximately 2-6 inches from the tubesheet face, or if the failure is of the type or magnitude that would render it impossible to repair, the tube must be renewed or plugged. The procedure used to renew a tube would be as follows: It is assumed that the tube bundle has been removed from the sodium shell, the closure head and internals removed and the entire assembly cleaned and prepared for retubing.

Step 1 - Using internal bore cutting equipment, cut the offending tube where indicated and remove from tube bundle.

Figure 3.6-2

The cut must be below the taper in order to remove the tube from the bundle.

Step 2 - Using internal bore machining equipment, machine new weld prep.

Figure 3.6-3

Depending upon location and type of defect, the new weld prep may be located within the limits shown.

Step 3 - Install new tubes through tube supports and fit up tube to tubesheet joint.

Figure 3.6-4

Step 4 - Using internal bore welding equipment, GTA first pass and balance of weld using filler wire.

Figure 3.6-5

Step 5 - Post heat treatment

Grind, clean up I.D.

Inspect - dye penetrant, ultrasonic, radiograph

Hydrotest

Plugging a High Pressure Tube - For a number of reasons it may be desirable to merely plug leaking tubes rather than repair or renew. A plugged tube should remain in the tube bundle to maintain the sodium side flow distribution. The metal temperature of a plugged tube will be that of the sodium while those surrounding it will be up to the sodium level and essentially that of saturated steam above that point, at a somewhat lower average temperature during operation. This is of no concern in a bayonet tube steam generator because the tube is attached at one end only and is completely free to expand axially independent of its neighbors.

It may be desirable to plug a tube temporarily until a scheduled maintenance outage when the tube may be repaired or renewed. The steps to be followed to plug a tube are as follows:

Step 1 - Insert plug and weld. (It is not established at this time what the final design of the tube plug should be. Complete access to the tube hole to be plugged and a wide choice as to type of plug are available. Some of the many possible designs are shown in Figure 3.6-6.

Figure 3.6-6

Step 2 - Post weld heat treatment

Step 3 - Inspect - dye penetrant, magentic particle

Step 4 - Hydrotest or leak test with Na side pressure

A tube plug is not nearly so simple to hydrostatic test as a repaired or replaced tube. A single tube may be pressurized simply by inserting an expandable plug in the tubesheet hole and pressurizing through a fitting in the plug. This, of course, cannot be performed easily on a plug similar to those shown in Fig. 3.6-6. Methods to hydrotest the plug without bolting up the top head are shown in Figures 3.6-7 and 3.6-8.

Figure 3.6-8

Figure 3.6-7

Nondestructive Testing - The inspection of a repaired tube, whether it is renewed, plugged or repaired, will include all applicable non-destructive tests. These include M.T., P.T., U.T., and R.T. The radiographic examination can be performed utilizing an iridium source as shown below. No double wall techniques will be required and high quality results can be obtained. The method for performing this radiography is illustrated in Figure 3.6-9.

Figure 3.6-9

As shown in this sketch, the film will be placed in the repaired tube and the iridium source placed in tubes numbered 1 through 6. Good radiographic sensitivity can be obtained by placing the source in tubes 1 through 6 to obtain full 360° exposure.

3.7 Rupture Disc Assembly

3.7.1

The rupture disc assembly for the secondary sodium/water reaction relief system is designed to connect the disc assembly to the twin 12 inch relief nozzles located in the gas space of the superheater and evaporator units. The design of the assembly will be terminated at the flange connection to the piping downstream of the rupture disc. The design of the vent piping system with a flange connection to the rupture disc assembly and the reaction products collection chamber are not included in the C-E follow-on program.

The follow-on program for the rupture disc assembly consists of detailed design and analysis of the rupture disc, the housing section and the instrumentation for detecting the rupture disc break. The design shall include detail drawings, procurement of materials, test of the disc assembly to verify rupture settings, and design and test of the detection instrumentation.

APPENDIX A

SPECIFICATION 30 Mw TEST MODEL

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REF: RDT STD E4-16T

30 MEGAWATT MODEL

MODIFICATIONS

EXCEPTIONS AND/OR INTERPRETATIONS TO

RDT E4-16T DATED MAY 1972

SODIUM HEATED STEAM GENERATORS

JANUARY 1973
COMBUSTION ENGINEERING, INC.

MODIFICATIONS**TABLE OF CONTENTS****1.0 SCOPE****2.1 Reactor Development and Technology (RDT) Standards****3.1.1.1 Purpose****3.1.1.3 Design Basis****3.1.3.1 Inspection****3.1.5 Seals****3.1.7 Drainability****3.1.7.2 Drain Line Sizes****3.2.1 Design Objectives****3.2.1.1 Design (general)****3.2.1.2 Stability and Flow Imbalance Analysis****3.2.5.1 Heat Transfer Surface****3.2.6 Decay Heat Removal****3.3.2.1 Design Conditions****3.3.16 Failure Analysis****3.4.8 Threaded Fasteners and Bolts****3.5.3 Water Level Indicators****3.10.3.2 Sodium Draining (secondary)****3.11 Reports and Documentation****3.11.1.1 (17) Failure Analysis**

**MODIFICATION EXCEPTIONS AND/OR INTERPRETATIONS TO RDT E4-16T
DATED MAY, 1972, FOR SODIUM HEATED STEAM GENERATORS**

This exceptions/interpretations document modifies, supplements or clarifies RDT Standard E4-16T dated May, 1972, and in conjunction with the Ordering Data, can be used to procure sodium heated steam generators.

1.0 SCOPE

Change first sentence to read:

This standard defines the requirements for the design, material selection, fabrication , testing and inspection of a test model of a sodium heated steam generator.

2.1 Reactor Development and Technology (RDT) Standards.Delete the following RDT Standards from this paragraph (not applicable).

RDT M 1 - 2T	3 - 11T
RDT M 1 - 6T	4 - 1T
2 - 1T	4 - 2T
2 - 4T	5 - 2T
2 - 7T	5 - 3T
2 - 8T	5 - 4T
2 - 15T	6 - 1T
3 - 4T	7 - 3T
3 - 5T	
3 - 6T	
3 - 9T	

Add the following RDT Standards to paragraph 2.1:

RDT M 1 - 10T
RDT M 7 - 4T

Section XI rules for in-service inspection dated 1971 and addenda through Summer, 1972.

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ASME Boiler and Pressure Vessel Code Case interpretations, code case 1331-7 Nuclear Vessels for high temperature service.

3.1.1.1 Purpose - Delete the paragraph and replace with the following: The model generator is a sodium to water steam heat exchanger whose purpose is to generate saturated/superheated steam by utilizing non-radioactive sodium as a heating medium and demonstrate the capabilities of the LMFBR demonstration plant steam generators.

3.1.1.3 Design Basis - Delete sentence beginning, "The required availability". Delete "refueling" from last sentence. Change comma to a period after "shutdown" and delete remainder of sentence.

3.1.3.1 Inspection - Delete the third and last sentences. This is not applicable due to the short servicelife of the test model.

3.1.5 Seals - Internal by-pass seals are not governed by this paragraph.

3.1.7.2 Delete last sentence.

3.2.1.1 Delete the third sentence and replace with the following: "The design shall incorporate features to eliminate or minimize such phenomena as thermal stratification, internal recirculation of sodium, and reverse flow of water-steam".

Item 5 - Delete "and dynamic".

Item 6 - Not applicable.

Item 7 - Not applicable.

3.2.1.2 Delete this paragraph: It is not planned to perform

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3.2.1.2 continued

these analyses for the steam generator test model.

3.2.5.1 Delete first sentence. For the purposes of the model testing, no excess surface or extra tubes will be included.

3.2.6 Delete this paragraph (not applicable).

3.3.2.1 Add paragraph as follows: The steam generator design pressures and temperatures shall be included in the Ordering Data.

3.3.16 Failure Analysis - Delete this paragraph. (It is not planned to perform this analysis for the test steam generator)

3.4.8 Threaded Elements and Bolts - Item 9 - Delete this requirement and replace with the following: Threaded or bolted connections on the sodium side shall be held to a minimum. Where bolted connections are required, suitable analysis shall be provided.

3.5.3 Water Level Indicators - Delete this paragraph. (In a forced recirculating steam generator utilizing a separate steam drum, the water level will be established within the drum and level indicators will be required in this component.

3.10.3.2 Sodium Drain - Delete this paragraph. (The SCTI has no facilities for rapid isolation and dump of the secondary sodium.)

3.11 Reports and Documentation - Add sentence: "Submittal of reports and Documentation shall be in accordance with Table IV".

3.11.1.1 Item 17 - Delete

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**REF: RDT STD E4-16T
DATED MAY 1972**

30 MEGAWATT MODEL

ORDERING DATA

**APPROXIMATE 30 MEGAWATT SODIUM HEATED
STEAM GENERATOR TO BE TESTED AT
THE SODIUM COMPONENT TEST INSTALLATION (SCTI)**

**SUPPLEMENTS RDT STANDARD E4-16T DATED MAY 1972
"SODIUM HEATED STEAM GENERATOR"**

**JANUARY 1973
COMBUSTION ENGINEERING, INC.**

SODIUM HEATED STEAM GENERATOR**APPROXIMATE 30 MEGAWATT STEAM GENERATOR FOR TESTING AT SCTI****ORDERING DATA****TABLE OF CONTENTS****1.0 SCOPE****1.1 Components and Services to be furnished****3.0 TECHNICAL REQUIREMENTS****3.1 General Requirements****3.1.1 Steam Generators****3.1.1.2 Type and Description****3.1.1.3 Design Basis****3.1.3 Inspectability and Maintainability****3.1.1.1 Inspection****3.1.6 Cover Gas****3.1.7 Drainability****3.1.7.2 Drain lines****3.1.8 Size and Weight****3.1.9 Preheating****3.1.9.2 Heatup rates****3.1.11 Performance Requirements****3.2 Thermal and Hydraulic Design Requirements****3.2.1 Design Objectives**

3.2.1.1 Specific Objectives**3.2.2 Type and Orientation****3.2.3 Physical Properties and Purity of Sodium****3.2.4 Physical Properties and Purity of Feedwater****3.2.5 Heat Transfer Surface****3.2.5.1 Excess Surface and Tubes****3.2.7 Pressure Drops****3.2.11 Thermal Transients****3.3 Structural Design Requirements****3.3.2 Stress Limits****3.3.2.1 Design Conditions****3.3.3 Seismic Requirements****3.3.4 Vibration****3.3.4.1 Flow ratio****3.3.6 Thermal Transient Stresses****3.3.7 Nozzle Loads****3.3.9 Baffles and Support Plates****3.3.9.2 Sizing****3.3.11 Sodium Water Reaction****3.3.14 Corrosion Allowance****3.4 Connections, Accessories and Appurtenances****3.4.2 Auxiliary Lines****3.4.3 Insulation Supports**

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2. Part Load steady state conditions
3. Dry heatup and cooldown
4. Normal Startup and Shutdown

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5. Load Changes
6. Step Changes
7. Other normal operating conditions

3.6.2.2 Upset Conditions

1. Normal Reactor plant
2. Loss of Recirculating pump flow
3. Other Upset Operating Conditions

3.6.3 Abnormal Conditions**3.6.3.1 Emergency Conditions**

1. Single Secondary Sodium pump Seizure with Scram
2. Single primary Sodium pump Seizure with Scram
3. Activation of Sodium-water Reaction Relief System
4. Loss of Feedwater Flow via Feedwater Control Valve Closure with Scram
5. Sodium-water Reaction Due to Single Tube Rupture
6. Steam Line Rupture
7. Other emergency conditions

3.6.3.2 Faulted Conditions**3.7.3 Materials****3.8.1 Fabrication****3.8.2.7 Tube Plug Welding****3.8.2 Heat Treatment****3.8.11 Assembly****3.8.13 Identification and Marking****3.8.13.3 Nameplates****3.9 Installation and Field Service Requirements****3.9.1 Services to be Provided****3.9.4 Handling****3.9.6 Installation Requirements**

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3. 10. 2. 3 Requirements for Pressure Relieving Devices**3. 12 Drawings****3. 12. 6 Parts List****4. 6. 2 Helium Leak Tests****5. 1 Items to be Delivered**

Table I Additional Requirements for Examination of Materials (RDT E4-16T)

Table II Range of Steady State Operating Conditions

Table III Drawing Submittal Requirements

Table IV Report and Document Submittal

Figure 1 Steam Generator Envelope

Figure 2 Schematic Arrangement of Steam Generator

Figure 3 Nozzle Loads

Figure 4 Normal Operating Ranges

Figure 5 Na/H₂O Flow vs % Power

Figure 6 Steam/Water Pressures vs % Power

Figure 7 Normal Load Changes

Figure 8 Normal Scram Transient

Figure 9 Secondary Sodium Pump Seizure

Figure 10 Primary Sodium Pump Seizure

Figure 11 Activation of NA/H₂O Protection System

Note: This document supplements the Sodium-Heated Steam Generator Standard RDT E4-16T, dated May, 1972. The numbering system used in this document is the same as RDT E4-16T. When no additional requirements to RDT E4-16T are required, the paragraph is omitted.

1. SCOPE

This document contains the Ordering Data to be used for the design and fabrication of a sodium heated steam generator to be tested in the Sodium Components Test Facility (SCTF).

1.1 Components and Services to be Provided - Components and services to be provided include the following items:

A complete steam generator as defined in 3.1.1, including:

- A. Structural supports
- B. Lifting lugs
- C. Drain, vent, and relief connections
- D. Preheat Requirements
- E. Tests and mockups to back up the design
- F. Drawings, plans and instruction manuals
- G. Design, analysis, and performance reports
- H. Quality Assurance procedures and documentation
- I. Spare parts
- J. Field services as defined in 3.9
- K. Insulation Requirements

1.1 Components and Services to be Provided continued**L. Steam Generator Instrumentation**

Associated equipment not covered by this specification: steam drum, pumps, piping, valves, sodium water reaction relief systems, control systems, isolation and dump systems.

3. TECHNICAL REQUIREMENTS**3.1 General Requirements****3.1.1 Steam Generator**

3.1.1.2 Type and Description - The approximate 30 megawatt thermal sodium steam generator shall be designed to model important design features and significant problem areas of the prototype steam generator. The steam generator shall consist of a bayonet-evaporator module and a bayonet superheater module as shown in Figure 1. The steam generator shall operate as a forced recirculation system as shown in Figure 2.

Feedwater shall enter the evaporator through nozzle H and flow downward through the bayonet tubes to the base of the tubes, where it shall flow upward through an annulus, receiving heat from the sodium on the shell side in counterflow. The steam shall then exit through nozzle G and after passing through a separator (not part of this specification), enter the superheater module through nozzle C.

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3.1.1.2 Type and Description continued

Entering the superheater, the steam shall flow downward through an annulus between the bayonet tube and pressure tube, receiving heat from the shell side sodium in counterflow. Upon reaching final superheat temperature at the base of the tube, the steam shall flow upward through the bayonet tube and exit the unit through nozzle D. The bayonet tube portion of the superheater tube assembly shall be made of double wall tubes to provide a stagnant space between the tubes for insulating purposes.

Sodium shall enter the lower portion of the superheater module through nozzle A and flow upward around the bayonet tubes and exit through nozzle B near the top of the bundle. The sodium shall then enter the upper part of the evaporator module through nozzle F and flow downward around the bayonet tubes and exit the evaporator at the lower end through nozzle E.

The steam generator shall be designed to incorporate an inert cover gas between the tubesheet and the sodium free surface in the evaporator and superheater modules. The cover gas systems in the modules are completely independent. Nozzles above and below the sodium level shall be incorporated to provide a means of measuring and controlling the sodium level in each module. A vent nozzle/s shall be provided at the highest points inside the module shells.

The steam generator design shall incorporate sodium-water reaction relief systems for each of the modules. Primary and secondary relief systems shall be connected to the modules at nozzles located in the gas space in each

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3.1.1.2 Type and Description continued

of the modules.

3.1.1.3 Design Basis - The steam generator shall be designed in accordance with the latest edition and addenda of the ASME Boiler and Pressure Vessel Code, Section III, together with the applicable code cases including Code Case 1331-7, the high-temperature criteria of RDT F9-1T, and the requirements of this specification. The steam generator shall be classified as a Class I vessel and shall be Code stamped. The steam generator shall be designed for a service life of 30 years operation at the conditions defined in 3.6.

3.1.3.1 Inspection - Requirements for In-Service Inspection (later).

3.1.6 Cover Gas - Argon cover gas shall be utilized above the surface of the sodium. The argon cover gas supply shall have the following characteristics:

Supply Inlet Temperature (°F)	100
Working Pressure (psia)	0 - 150
Purity	99.996%

<u>Impurities</u>	<u>PPM</u>
Oxygen (tentative)	5
Hydrogen (tentative)	2
Nitrogen	15
Carbonaceous Gases	5
Water (D. P. - 84°F)	6
Other	7

3.1.7.2 Drain lines will be 2" pipe size.

3.1.8 Size and Weight - The approximate size and weight of

3.1.8 Size and Weight continued

the steam generator are shown in Figure 1.

3.1.9.2 The heatup rate of the steam generator shall be 5°F/hr. from ambient to 350°F.

3.1.11 Performance Requirements - The steam generator shall be capable of continuous operation through the range of conditions specified in 3.6. The steam generator shall be designed for exposure to the following environmental conditions after installation and during operation:

Ambient Temperature	18 - 109°F
Ambient Pressure	27.5 - 28.5" HG
Ambient Humidity	100%
Nuclear Radiation Intensity	none
Neutron Radiation	none

3.2 Thermal and Hydraulic Design Requirements**3.2.1 Design Objectives**

3.2.1.1 The steam generator shall be designed to permit safe, stable, and predictable operation throughout the load range of the steady state and transient conditions presented in 3.6.

3.2.2 Type and Orientation - The steam generator shall be forced recirculating shell and bayonet tube heat exchanger with sodium on the shell side and water/steam on the tube side. The superheater and evaporator shall be contained in separate shells each mounted separately in a vertical position as shown in Figure 1.

3.2.3 Physical Properties and Purity of Sodium - For the steam generator design, the sodium properties as recommended in ANL-7323 shall be used. Limitations, if any, of the SCTI will be factored into this

3.2.3 Physical Properties and Purity of Sodium continued

specification at a later date.

3.2.4 Physical Properties and Purity of Feedwater - The feedwater

purity limits for the steam generator model shall be as follows:

	PPB
1. Total dissolved solids	200
2. Total silica	10
3. Total iron	40
4. Total copper	190
5. Conductivity after ion exchange	5 - 1.5 mho
6. PH	8.5 to 9.2

Limitations, if any, of the SCTI will be factored into this specification at a later date.

3.2.5.1

Excess surface	0
Extra Tubes	0

3.2.5.2 - The steam generator sodium level control system will be designed to maintain the sodium level with a permissible variation from the set point of plus or minus 3 inches.

3.2.7 - Pressure Drop - The water/steam side and sodium side pressure drop shall not exceed the following:

Water/steam side, evaporator	50 psi
Water/steam side, superheater	125 psi
Sodium side, evaporator	20 psi
Sodium side, superheater	20 psi

3.2.11 Thermal Transients - An analysis shall be performed to evaluate the response of the steam generator to the inlet flow and temperature transients of water and sodium specified in Section 3.6

3.3 Structural Design Requirements

3.3.2 Stress Limits - Allowable stresses for the steam generator shall be in accordance with Section III of the Code, Code case 1331-7 and RDT F9-1 for a service life of 30 years under the normal, upset, emergency, and faulted conditions specified in 3.6.

3.3.3 Seismic Considerations - Earthquake zone 3

DBE Acceleration	.2G Horizontal	acting
	.1G Vertical	simultaneously

3.3.4 Vibration

3.3.4.2 Flow rates for use in vibration analyses shall be 110% of the maximum flow rates specified in table II.

3.3.6 Thermals Transient Stresses - Regions of discontinuities such as nozzles, tube to tubesheet joints, tubesheet to shell regions, and thick sections such as tubesheets, nozzles, and shells shall be analyzed for thermal stresses resulting in part from the number of sodium and water-steam temperature transients specified in Section 3.6.

3.3.7 Nozzle Loads - Nozzle loads shall be in accordance with Figure 3.

3.3.9.2 Tube bundles, baffle and tube support thickness, and tube hole clearances shall meet the requirements of the specifications, codes and code cases contained in paragraph 3.1.1.3.

3.3.11 Sodium-Water Reaction - The steam generator shall be designed to contain the pressure and shock forces caused by the design basis leak (DBL) defined below:

3.3.11 Sodium-Water Reaction continued

One (tentative) guillotine failure of pressure tube at the worst location as determined by a sodium-water reaction pressure loading analysis.

3.3.14 Corrosion Allowance - Later**3.4 Connections, Accesses, and Appurtenances****3.4.2 Auxiliary Lines - See 3.4.7**

3.4.3 Insulation Supports - The supplier shall provide insulation supports on the exterior surfaces of the steam generator evaporator and superheater shells. Integral clips or rings for supporting the insulation shall be provided prior to final heat treatment.

Requirements for insulation shall be established by the supplier based upon the following criteria and operating conditions. (Later)

3.4.6 Foundation and Support Structure - (Later)

3.4.7 Piping Connections - The interface location of the sodium and water/steam lines and auxiliary lines are shown in Figure 1. Piping sizes, end preparation and number required shall be as follows:

	<u>No. Required</u>	<u>Pipe Size</u>	<u>End Preparation</u>
Sodium inlet, superheater	1	10"	Butt Welded
Sodium inlet, Evaporator	2	6"	Butt Welded
Sodium outlet, evaporator	1	10"	Butt Welded
Sodium outlet, superheater	2	6"	Butt Welded
Evaporator recirc. water inlet	1	8"	Butt Welded
Evaporator saturated steam outlet	1	8"	Butt Welded
Superheater saturated steam inlet	1	6"	Butt Welded
Superheater steam outlet	1	8"	Butt Welded

3.4.7 Piping Connections continued

Auxiliary Lines (in each evap/S. H. module)

	<u>No. Required</u>	<u>Pipe Size</u>	<u>End Prep.</u>
Sodium Level Nozzles	Later		Butt Welded
Primary Relief Nozzles	Later		Butt Welded
Secondary Relief Nozzle	2	12"	Butt Welded
Cover Gas Makeup & Vent Nozzle	1	1"	Butt Welded
Vent (steam/water)	1	1"	Butt Welded
Instrumentation	1	2"	Butt Welded

3.4.9 Preheating System Supports - (Later)

3.5.1.1 The following instruments and provisions for instrumentation are considered to be a part of the steam generator and consist of the following:

- a. Strain gages for measurement of shell stresses
- b. Sodium level indicators
- c. External sodium leak detection
- d. Water-to-sodium leak detectors
- e. Pressure indicator
- f. Vibration instrumentation
- g. Temperature indicator

Numbers and location of instrumentation (Later)

3.5.2 Sodium Level Indication - The steam generator shall be fitted with independent sodium level indicators mounted external to the evaporator and superheater shell modules.

3.5.4 Pressure Gages - The requirements of the pressure gages to measure sodium and water/steam pressures shall be determined and provided by the supplier for installation in the piping adjacent to the steam generator model.

3.5.5 Temperature Instrumentation - Requirements for the temperature

3.5.5 Temperature Instrumentation (continued)

instrumentation necessary to establish the thermal and structural performance of the steam generator model shall be determined by the supplier.

Thermocouples shall be installed on the steam generator model to adequately measure the following:

- a. Sodium side temperature
- b. Water/steam side temperature at end points
- c. Shell temperature

Requirements and location of temperature measuring devices shall be as follows: (Later)

3.5.6 Requirements for flow measurement shall be provided by the supplier. No flow measurement will be required within the steam generator shells.

3.5.7 Water-to-sodium Detection - The evaporator and superheater modules of the steam generator shall have provisions for two (2) independant means of monitoring for water-to-sodium leakage.

1. Diffusion tube Hydrogen detectors shall be located in the sodium piping as close as practicable to the superheater outlet nozzles and the evaporator outlet nozzle.
2. The cover gas space in the evaporator and superheater modules shall have provision for continuous monitoring of the cover gas by means of a gas chromatograph to detect hydrogen.

3.5.8 External Leakage Detection - (Later)

3.5.9 Instrumentation, Inspection, Maintenance, and Repair - Test procedures to determine the functional operation of instrumentation shall be provided by the purchaser.

3.5.10 Structural Instrumentation - The supplier shall determine the requirements of instrumentation necessary to determine the structural performance of critical areas of the steam generator. This instrumentation shall be provided as part of the steam generator. Procedures for installation of instrumentation will be provided by the supplier.

3.6 Operating Conditions

Note: (The information and criteria in this section is of a preliminary nature and is not in the form that will be contained in the final specification. Some of the notations and discussions are included for preliminary information only and will be deleted in the final spec. Tables will replace the curves shown in figures 4 through 11).

3.6.1 Types of Operating Conditions - The steam generator shall be designed and fabricated for satisfactory operations under the normal, upset, emergency and faulted conditions as defined in paragraph NB-3113 of Section III of the ASME Code and as specified below in Sections 3.6.2 and 3.6.3. These operating condition categories are defined in summary in the following paragraphs.

3.6.1.1 Normal Conditions - Normal conditions are any conditions experienced in the course of system startup, operation in the design power range, hot standby and system shutdown, other than Upset, Emergency, Faulted or Testing Conditions.

3.6.1.2 Upset Conditions - Any deviations from Normal Conditions anticipated to occur often enough that design should include a capability to withstand the conditions without operational impairment are

3. 6. 1. 2 Upset Conditions continued

called Upset Conditions. The Upset Conditions include those transients which result from any single operator error or control malfunction, transients caused by a fault in a system component requiring its isolation from the system and transients due to loss of load or power. Upset Conditions include any abnormal incidents not resulting in a forced outage and also forced outages for which the corrective action does not include any repair of mechanical damage.

3. 6. 1. 3 Emergency Conditions - Emergency Conditions are those deviations from Normal Conditions which require shutdown for correction of the conditions or repair of damage in the system. The conditions have a low probability of occurrence but are included to provide assurance that no gross loss of structural integrity will result as a concomitant effect of any damage developed in the system. The total number of postulated occurrences for such events shall not cause more than 25 stress cycles having an Sa value greater than that for 10^6 cycles from the applicable fatigue design curves.

3. 6. 1. 4 Faulted Conditions - Faulted conditions are those combinations of conditions associated with extremely-low-probability, postulated events whose consequences are such that the integrity and operability of the nuclear energy system may be impaired to the extent that considerations of public health and safety are involved. Such considerations require compliance with safety criteria as may be specified by jurisdictional authorities.

3. 6. 2 Steady-State and Transient Operation - The steam generator shall perform under steady-state operational and environmental conditions, including transients induced by varying loads. It shall also operate under other operational transients which are not steady-state conditions. All of these operating conditions are defined in the following paragraphs.

3. 6. 2. 1 Normal Conditions

1. Full Power Steady-State Operating Conditions -

The steam generator full power steady state operating conditions are shown in Table II.

2. Part Load Steady-State Operating Conditions -

The steam generator part load steady-state operating conditions of temperature flow and pressure are shown in Table II and the curves on Figures 4, 5 and 6.

3. Dry Heatup and Cooldown - Dry heatup and

cooldown rates of the steam generator shell are shown in the following table. Heatup of the shell is accomplished by trace heating prior to filling with sodium.

Event	Location	Temp. °F		No. of Occurrences	Temperature Change
		Start	End		
Dry Heatup	Shell	Ambient	350°F	10	+ 5°F/hr.
Dry	Shell	350°F	Ambient	10	- 5°F/hr.

4. Normal Startup and Shutdown - The normal startup

and shutdown temperature transient conditions are specified in the following table. The temperature change rates shown apply specifically to the inlet

3.6.2.1 Normal Conditions continued

nozzles on both the sodium and water/steam sides.

Event	Location	Temp. °F		No. of Occurrences	Max. Rate of Temp. Change
		Start	End		
Startup	Sodium Inlet Nozzle	350°F	924°F	600	+100°F/hr.
	FW Inlet Nozzle @ Drum	100°F	370°F		
Shutdown	Sodium Inlet Nozzle	924°F	350°F	250	-100°F/hr.
	FW Inlet Nozzle @				
	Drum	370°	100°F		

During the startup transient sodium flow is held constant at 30% to 35% power and then increased linearly to 40% flow at 40% power. The flow and power transients during shutdown are the reverse of those given for startup. (Feedwater flow, temperature and pressure during startup and shutdown will be determined later).

5. Load changes Over the 40 - 100% Power Range -

The steam generator will be subjected to two types of load changes, i.e. step changes in load and ramps

a. Normal Ramp Change - Normal ramp load changes will vary linearly between the end conditions at 40% and 100% full power with a power ramp rate of 3%/min. Temperature change rates are shown in the table below. Sodium and feedwater flows vary from 39.5% to 100% and 37% to 100% respectively over this power range. This information is summarized in Figure 7 for a normal load decrease from 100% to 40%.

A load increase over the same range is simply the reverse of these curves.

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Additional temperature ramps over different load ranges can be obtained from the part load operation curves shown in Figures 4, 5 and 6.

Event	Location	Temp., °F		No. of Occurrences	Max. Rate of Temp. Change
		Start	End		
Normal Power Increase	Sodium Inlet Nozzle	924	960	9000	1.8°F/min.
	FW Inlet Nozzle @ Drum	370	460		4.5°F/min.
Normal Power Decrease	Sodium Inlet Nozzle	960	924	9000	-1.8°F/min.
	FW Inlet Nozzle @ Drum	460	370		-4.5°F/min.

*Temperature transients at other locations within the steam generator will be available later.

b. Step Changes - It is assumed that the demonstration plant must be capable of performing step changes in power which are at least equivalent to those provided for in current water reactor plants. Therefore, the step change is based on a $\pm 10\%$ instantaneous change in power from any power level over the 40% - 100% power range. The response of the plant to these steps should be as quickly as possible. However, the rate of change of temperature, pressure and flow has not been determined and will be supplied later. The C-E PWR's specify that these step changes exhibit temperature and pressure fluctuations within the range of their normal specified plant variations. The normal demonstration plant variations are not available, therefore, this information will be supplied later. The number of occurrences is estimated to be 1500, equally divided between upswings and downswings.

c. Fast or Emergency Ramp Power Changes - (Later)6. Other Normal Operating Conditions - There are

several other operating conditions that are considered normal but are not included here because it is felt that they are similar in transient response to some of those already listed. These operating conditions would include such things as: Hot Restart after Scram, Shutdown after Scram, or the Return to Power from Hot Standby or the reverse, i.e., going to Hot Standby condition from Power Operation. All of these transient conditions are similar to or a combination of either normal startup and normal power increases over the load range or the reverse, which is normal power decreases and normal shutdown. Therefore, they have been accounted for by increasing the number of occurrences of the appropriate normal operating condition.

3.6.2.2 Upset Conditions - The following transients are defined as upset conditions and are considered to be representative of most the group of possible upset events. Included are curves showing the expected thermal transients in the fluid at the sodium and feedwater inlet nozzles and their estimated number of occurrences. The thermal transients at other locations throughout the steam generator are currently being evaluated.

1. Normal Reactor Plant Scram - (Number of Lifetime Occurrences = 350) Reactor plant scram is an operating procedure for very quickly reducing the power output of the reactor to a low level of

2-5% as determined by fission product decay heat. This scram might

3. 6. 2. 2 Upset Conditions continued

be a result of a false spurious electrical signal or a desired response from one of many protective system signals or an operator-initiated signal. The reactor scram primarily consists of reducing the reactor power by dropping all control rods, and simultaneously reducing the heat transfer system flows by tripping the primary and secondary sodium pumps and the feedwater pumps. The secondary sodium flow coasts down to 5% while the feedwater flow coasts down to 4%. These flow decay curves and the sodium and feedwater inlet temperature transients for the first 300 seconds following scram are shown in Figure 8. Also shown is the feedwater inlet pressure drop of 200 psi which varies with the square of the flow. Furthermore, when scram occurs, the turbine-generator is also tripped. After the 300 seconds shown on the curves, the transient is assumed to follow the normal shutdown transient.

2. Loss of Recirculation Pump Flow - (Number of lifetime occurrences = 20 pump) Definition of transient - (Later)

3. Other Upset Operating Conditions - It is recognized that there are a number of other operational events that are considered to be Upset Conditions. However, at this time since they all would very quickly cause a reactor scram, it is assumed that the transients would be similar to a scram transient. Therefore, allowance has been made for these events by appropriately adjusting the number of occurrences of the normal scram. Some of the other Upset Conditions include events such as: positive reactivity insertion with scram; loss of electrical power to one

3.6.2.2 Upset Conditions continued

primary, secondary or feedwater pump with scram, loss of plant power with scram, control rod drop with scram, and turbine trip with scram. It is recognized that the scram following some of these events might be delayed somewhat and therefore, momentary up or down temperature transients could be initiated. However, from past experience these have been found to be quite short in time and have very little effect on the overall temperature transient used for structural analysis. Therefore, since these delays were not identified at this time, no attempt was made to include them and all such events are assumed to be similar to a normal scram. It should be pointed out that as additional plant system design information becomes available, these Upset Conditions will be reconsidered and if this assumption appears invalid in any of the cases, the transient will be considered separately.

3.6.3 Abnormal Conditions - Abnormal conditions are classifiable as occurring after a failure or malfunction of a component or system. Although no longer stated as an operating category in the ASME Code, the events under this section in the RDT Standards include events which now fall under Faulted, Emergency and in some cases, Upset Condition categories of the ASME Code. Since some Upset Conditions were also listed under section 3.6.2 - "Steady-State and Transient Operation" of the RDT standards above, e.g., reactor scram, it was decided to include all Upset Conditions under that category. Therefore, only Emergency and Faulted

3.6.3 Abnormal Conditions continued

Conditions will be included in this section.

3.6.3.1 Emergency Conditions - The following transients are defined as Emergency Conditions and are representative of a group of possible events but do not include all such events. Included here, similar to what was done previously for Upset Conditions, are curves showing the expected thermal transients in the fluid at the sodium and feedwater inlet nozzles and their estimated number of occurrences. The transients at other locations throughout the steam generator are currently being determined and will be available in the near future.

1. Single Secondary Sodium Pump Seizure with Scram - (Number of Lifetime Occurrences = 3 per loop) The seizure of one secondary sodium pump is quite similar to a normal scram, with the exception of the flow coastdown in the affected loop. Since the pump shaft is assumed to seize quickly, the impellar stops rotating and therefore creates an additional resistance in the loop flow. This is assumed to cause a flow coastdown twice as fast as a normal loop coastdown. The sodium inlet temperature to the steam generator of the affected loop will remain constant over the first 300 seconds. Feedwater parameters are identical to those occurring during normal scram. All of these steam generator inlet parameters for the affected loop are shown in Figure 9. Parameters in the other two secondary sodium loops and associated feed-

3.6.3 Abnormal Conditions continued

water systems are identical to normal reactor scram, since scram is assumed to occur a few instants after pump seizure. After the 300 sec. shown on the curves, the transient is assumed to follow the normal shut-down transient.

2. Single Primary Sodium Pump Seizure with Scram -

(Number of Lifetime Occurrences - 3 loop) The steam generator inlet conditions for the first 300 seconds of this transient are shown in Figure 10. Everything is the same as normal scram with the important exception of sodium inlet temperature which eventually decreases at a rather high rate of $-3^{\circ}\text{F}/\text{sec}$. This temperature ramp is caused by the stoppage of the primary flow in the seized loop caused by closure of the check valve. That is, once flow in that primary loop is essentially stopped, the secondary sodium loop, even at low decay heat flows, rapidly removes the stored heat in the IHX primary sodium. The reduction in primary sodium temperature causes a similar reduction in secondary sodium temperature which eventually levels out near the steam saturation temperature. Sodium and feedwater flows, temperatures and pressures in the two other main heat transfer loops are the same as for normal scram. Furthermore, after the 300 seconds shown on the curves of Figure 10, the transient is assumed to follow the normal shutdown transient.

3. Activation of Na/H₂O Protection System - (Number of Lifetime Occurrences - 2 per component - evaporator/superheater pair)

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3.6.3 Abnormal Conditions continued

This event consists of an emergency isolation and dump of the water/steam side of an evaporator/superheater module pair during power operation. Following the initiation of such an event, a reactor plant scram will occur, probably triggered by a loss of pressure signal of the effected steam generator. For this transient, a delay of 5 seconds is assumed before scram occurs. The sodium inlet nozzle temperature and flow transients are therefore similar to normal scram and are illustrated in Figure 11. The feedwater parameters will also vary according to normal scram conditions with a 5 second delay; however, this transient is not influenced by feedwater conditions since the water/steam sides are isolated. Instead, when the isolation valves close and the dump valve opens, the water/steam mixtures will quickly blow down. This occurs in both the evaporator and superheater modules simultaneously since the protection system of each pair is tied together. These blowdown flows are currently being determined and are not yet available. Therefore, the internal temperature transients in the steam generator during and after blowdown have not been determined. They will be supplied in the near future. Again, as before, after the first 300 seconds, the transient is assumed to be similar to the normal scram transient.

4. Loss of Feedwater Flow Via Feedwater Control Valve

Closure with Scram - (Number of Lifetime Occurrences = 2 valves) Although the operating philosophy for this event has not been completely defined yet, it is included and briefly discussed here because of the possible effects it might have on the steam drum, the evaporator, and recirculation pump designs. This event is different from the loss of feedwater pump power event in that the

3.6.3 Abnormal Conditions continued

closing of the feedwater control valve stops all feedwater flow whereas 4% natural convection flow still remained after loss of pump power. With the complete loss of feedwater flow to the steam drum, the drum level can drop, possibly to a point where the recirculation pumps began to cavitate. This condition could damage the pumps. Furthermore, with no low temperature feedwater entering the drum, the drum water temperatures will begin to rise as a function of the recirculation water temperature only. This will cause temperature transients on the drum as well as the evaporator. It is probably possible to eliminate this possible transients by proper operating procedures and/or a backup feedwater supply, however, this has not yet been determined. Therefore, the transient, if any, during this event will be defined later.

5. Sodium-Water Reaction Due to a Design Basis Leak -

The pressure, flow and temperature transients during this event will be defined later.

6. Steam Line Rupture (Loss of Pressure) - This

transient has not been defined yet and will be supplied later.

7. Other Emergency Operating Conditions - Several

other events which might be considered to fall within this category by some designers are briefly discussed in this section. The RDT standard lists four additional events including: loss of primary sodium, loss of secondary sodium, loss of operating power, and scram with sodium flow continuing. The first two events could include two initiating conditions, both of which have been already

3.6.3 Abnormal Conditions continued

discussed and specified. This is, the loss of primary or secondary flow can be caused by power failure to the pumps which is similar in transient response to reactor scram and is included under Upset Conditions.

This event could also be caused by seizure of a pump as was discussed above under Emergency Conditions. The third event, loss of operating power is similar in response to reactor scram and is included under Upset Conditions. The last event, i.e., scram with sodium flow continuing, has been precluded by the control philosophy of the demonstration plant. That is, sufficient backup trip circuits will be provided to insure that all pumps trip whenever scram occurs.

3.7.3 Material Samples - (Later)

3.8.1 Fabrication - Submittal of drawings and documents shall be in accordance with tables 3 and 4.

3.8.2.7 Tube Plug Welding - Tests to demonstrate tube plugging procedures and equipment shall be performed by the supplier. The type and number of these demonstration acceptance tests shall be submitted to the purchaser for approval.

Tube plugs to be furnished by supplier (Later).

3.8.3 Heat Treatment - Heat treatment procedures shall be submitted for purchaser approval prior to heat treatment. Six copies of heat treatment records shall be submitted. Number of copies is shown in Table 4.

3.8.11 Assembling - An inspection and assembly procedure shall be submitted by the supplier for purchaser approval.

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3.8.13 Identification and Marking

3.8.13.3 Nameplates - Nameplates shall be installed on both modules on stand-offs in an accessible location to permit reading after insulation is applied. In addition to the ASME Code requirements for marking, the nameplates shall include the following data:

Part Name
Identifying No.

Contract No.
C-E Spec. No.

3.9 Installation and Field Services Requirements

3.9.1 Services to be Provided - The supplier shall provide the services of a field representative to monitor installation, pre-operational testing, repair, performance of test program and to provide technical advice during these operations. Specific requirements will be determined later.

3.9.4 Handling - The supplier shall provide all fixtures and equipment necessary to handle the steam generator components. These include:

- Shipping saddles, covers, tie downs, etc.
- Fixtures necessary for up-ending the components at the site
- Equipment for maintaining a positive pressure inert gas atmosphere on the interiors of the components during shipment and storage.

3.9.6 Installation Requirements - The supplier shall monitor the off-loading of the steam generator at the site and the up-ending, lifting and installation of the components in the facility.

The supplier shall monitor the installation of all instrumentation furnished by the supplier.

3.10.2.3 Requirements for pressure relieving devices - (Later)

3.12 Drawings - The time, number of copies, and approval require-

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3.12 Drawings continued

ments for drawings shall be in accordance with Table 3.

3.12.6 Parts List - Spare tube plugs to be furnished - See paragraph

3.8.2.7.

4.6.2 Helium Leak Testing - Acceptance standards and specific requirements (Later).

5.1 Preparation - Items to be delivered (Later).

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. _____
 DESCRIPTION _____

NUMBER _____
 SHEET _____ OF _____
 DATE _____ BY _____
 CHECK DATE _____ BY _____

FIGURE I

FIGURE 2
Schematic Arrangement
Bayonet Tube Evaporator Drum & Superheater

FIGURE 3

STEAM GENERATOR SYSTEM TEMPERATURES
AS A FUNCTION OF POWER
FOR AEC DEMO PLANT UNIT

FIG. 4

FIG. 5

STEAM GENERATOR SYSTEM PRESSURES
AS A FUNCTION OF POWER FOR
A.E.C. DEMO PLANT UNIT

FIG. 6

FIG. 7

FIG. 8

FIG. 9

FIG. 10

FIG. 11

TABLE II B

RANGE OF STEADY STATE OPERATING CONDITIONS

CONDITION				
	100% Power	80	60	40
Heat Load, MWt	26.7	21.4	16	10.7
<u>SODIUM SIDE</u>				
Sodium Flow Rate (lb. /hr.)	1.02X10 ⁶	.880x10 ⁶	.700x10 ⁶	.486x10 ⁶
Sodium Inlet Temp. (°F)	960	945	933	926
Sodium Outlet Temp. (°F)	673	665	658	656
Sodium Inlet Pressure (psig)		Later		
Sodium P (psi)	18	11.5	6.5	2.9
<u>STEAM-WATER SIDE</u>				
Feedwater Flow (lbs. hr.)	.965x10 ⁵	.772x10 ⁵	.58x10 ⁵	.385x10 ⁵
Feedwater Temp. (°F)	460	440	412	370
Feedwater Pressure (psia)	2666	2624	2590	2563
Recirculation Ratio	3.5	4.0	6.0	9.0
Steam Outlet Temp. (°F)	900	900	900	900
Steam Outlet Pressure (psig)	2500	2500	2500	2500

DESIGN CONDITIONS

TABLE II B

Item	<u>Superheater</u>	<u>Evaporator</u>
	Design Press/Temp.	Design Press/Temp.
Heat transfer tubes	2600 psia/960⁰F	2700 psia/866⁰F
Tubesheet	2700 psia/750⁰F	2750 psia/750⁰F
Sodium shell	250 psia/960⁰F	250 psia/866⁰F
Channel shell	2700 psia/750⁰F	2750 psia/750⁰F

TABLE 3

DRAWING SUBMITTAL REQUIREMENTS

ITEM	DESCRIPTION	NO. OF REPRODUCIBLE DOCUMENTS REQUIRED	REF.	SUBMIT FOR APPROVAL INFO.	TIME OF SUBMITTAL
1.	Preliminary Outline Drawings Initial Submittal Final Submittal				
2.	Assembly Drawings Initial Submittal Final Submittal				
3.	Final Outline Drawings				
4.	Detail Drawings				
5.	Drawings & Spec. List				
6.	Paris List				
7.	Weights and Center of Gravity				

TABLE 4

REPORTS AND DOCUMENTS SUBMITTAL

ITEM	DESCRIPTION	NO. OF REPRODUCIBLE DOCUMENTS REQUIRED	REF.	SUBMIT FOR APPROVAL INFO.	TIME OF SUBMITTAL
1.	Design Reports				
2.	Interim Reports				
3.	Q. A. Program Plan				
4.	Inspection and Test Plan				
5.	Process Special Control & NDT Procedures				
6.	Inspection & Test Procedures				
7.	Nonconforming Item Documentation				
8.	Handling, Pres. , Packing, & Storage Procedures				
9.	Proposed New Design Criteria				
10.	Design Description				
11.	Quality Records				
12.	Periodic and Progress Reports				
13.	Operations and Maintenance Manual				

APPENDIX B

SPECIFICATION - WATER/STEAM RECIRCULATING LOOP

SPECIFICATION
FOR
THE STEAM GENERATOR WATER/STEAM CIRCULATION SYSTEM
FOR
THE 30 MEGAWATT SODIUM STEAM GENERATOR TEST MODEL

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- B. Parameters
- C. Drawings
- D. Instrument List
- E. Valve List
- F. Equipment List
- G. Specification for Steam Drum
- H. Specification for Recirculating Pump
- J. Specification for Recirculating Pump Suction and Discharge Valves
- K. Demonstration Plant Steam Generator RDT Standard Specifications Section 3.6, Operating Conditions

1.0 SCOPE

This specification defines the requirements for the design, material selection, fabrication, testing, inspection and installation of the water/steam circulation system for the 30 Mwt Sodium Heated Steam Generator Test Model in the SCTL facility.

1.1 Abbreviations and Acronyms

- A. LMFBR - Liquid Metal Fast Breeder Reactor
- B. SGWCS - Steam Generator Water/Steam Circulation System
- C. ASME - American Society Mechanical Engineering
- D. ANSI - American National Standards Institute
- E. RDT - Reactor Development Technology
- F. AEC - Atomic Energy Commission
- G. MCR - Maximum Continuous Rating
- H. CR - Circulation Ratio

1.2 Purpose of Equipment

SGWCS equipment is an integral part of the 30 Mwt Sodium Steam Generator Test Model design. The test model and the SGWCS represents the C-E design of the steam generator system for the LMFBR Demonstration Plant.

A test of the steam generator model and the SGWCS is required to verify the design.

The SGWCS shall receive heat from the secondary sodium loop by means of an evaporator and superheater. The SGWCS, using the principle of water recirculation in the evaporator section of the steam generator, shall produce a reliable supply of superheated steam to verify performance and operation of the SGWCS and the test model.

The SGWCS contains one (1) sodium heated evaporator, one (1) sodium heated superheater, steam drum, recirculating pump, valves and connecting piping. (See SGWCS Schematic Arrangement - Appendix "C").

1.3 Components and Services to be Provided

A. The following components and systems are not included in this specification but will be installed as part of the SGWCS design.

- (1) The evaporator and superheater units
- (2) Evaporator and superheater vessel inlet and outlet isolation valves.
- (3) Evaporator and superheater vessel dump valves.
- (4) The water/steam dump system.
- (5) The SGWCS control system.

B. The terminal points of the SGWCS are defined as follows:

- (1) SCT1 feedwater connection to the steam drum

- (2) The evaporator inlet nozzles
- (3) The evaporator dump valves
- (4) The evaporator outlet nozzles
- (5) The superheater inlet nozzles
- (6) The superheater dump valves
- (7) The superheater outlet nozzles
- (8) The superheated steam line downstream of the isolation valve connecting to the SCT1 desuperheater pipe.

C. The Components and services that shall be supplied in installing the SGWCS into the SCT1 facility are:

- (1) Instrumentation with connections
- (2) High pressure piping
- (3) Thermal insulation of the piping and components
- (4) Water recirculating pump
- (5) Structural attachments and lifting lugs
- (6) Drain and vent connections with double valves
- (7) High pressure safety valves
- (8) Terminal points containing butt weld end connections
- (9) Drawings and instruction manuals
- (10) Meeting requirements of RDT Standards and Code Procedure Commitments, such as reports, certifications, tests, etc.
- (11) Special tools and spare parts, as required
- (12) Services of an engineer to supervise the Steam Generator Water/Steam installation and to instruct personnel in operation and maintenance of the system.

(13) Delivery of equipment to the plant site

D. Components and services that will not be supplied during the installation of the SGWCS into the SCTL facility are:

- (1) Piping downstream of the drain and vent double valves, safety valve discharge piping and silencers
- (2) Recirculating pump miscellaneous low pressure piping
- (3) Unloading, storage, field erection labor, crane service, rigging and logging, and tools (except for those special tools furnished with the SGWCS)
- (4) Foundation and structure for supporting the SGWCS.

2.0 APPLICABLE DOCUMENTS

The following documents are a part of this specification except where specified herein. Those amendments in effect on specification date issue, shall only apply unless otherwise specified. Where the specification appears to conflict with the requirements of the referenced document, such conflict shall be brought to the attention of the specification issuer for resolution.

2.1 Reactor Development and Technology (RDT) Standards

Identification No.

RDT C 7-2T*	Thermocouple Material, Iron-Constantan, Magnesium-Oxide Insulated, Sheathed
RDT C 7-4T*	Thermocouple Material, Iron-Constantan, Magnesium-Oxide Insulated, Sheathed
RDT C 7-6T*	Thermocouple Assembly, Nuclear Grade, Chromel-P vs Alumel, Stainless Steel Sheathed, Magnesium-Oxide Insulated
RDT E 15-2T	Requirements for nuclear components (supplement to ASME Boiler and Pressure Vessel Code, Section III).
RDT F 2-2T*	Quality Assurance Program Requirements
RDT F 3-6T*	Non-Destructive Examination
RDT F 3-37T*	Special Requirements for Metal Products
RDT F 4-20T*	Operation and Maintenance Manuals
RDT F 5-1T*	Cleaning and Cleanliness Requirements for Nuclear Requirements
RDT F 6-5T*	Welding Qualifications (Supplement to ASME Boiler & Pressure Vessel Code, Section IX)

* "T" which appear at the end of RDT Standard numbers designates approval for use as a "Tentative" standard.

Identification No.

RDT F 6-7T*	Requirements Concerning Welding
RDT F 6-10T*	Repair of Materials by Welding
RDT F 6-11T*	Requirements for Subassembly Fabrication and Marketing
RDT F 7-2T*	Preparation for Sealing, Packaging, Packing and Marking of Components for Shipment and Storage
RDT F 7-3T*	Requirements for Identification marking of Reactor Plant Components and Piping
RDT F 8-1T*	Pre-loading Threaded Fasteners and Closures
RDT F 8-6T*	Requirements for Hoisting and Rigging.
RDT F 9-1T*	Requirements for Nuclear Components at Elevated Temperatures (Supplement to ASME Elevated Temperature Code 1331)
RDT 2-4T*	Requirements for establishing and execution of a program by the contractor to verify the quality of items and services
RDT 2-4T*	Calibration System to Control Accuracy of Measurement and Test Equipment All material standards that are applicable to the SGWCS design (Additional standards will be identified later).

2.2 American Society of Mechanical Engineers (ASME) Codes

The following ASME Boiler and Pressure Vessel Code with Addenda and applicable Code Cases shall apply to the design of the SGWCS:

a)	Section I	Power Boilers	All piping and components except superheater outlet piping
b)	Section I
ANSI B 31.1.0	Power Piping	Superheater Isolation valve and downstream piping
c)	Section III
Class 1	Power Boilers	To isolation valves of
a) evaporator inlet pipe
b) evaporator outlet pipe
c) superheater inlet pipe
d)	Section III
Class 1
Code Case 1331-7	Power Boilers	From superheater outlet pipe to isolation valve
e)	Section IX	Welding Qualifications	

2.3 American National Standards (ANSI) Standards

ANSI B1.1	Unified Screw Threads
ANSI B16.9	Wrought Steel Butt Welding Fittings
ANSI B16.26	Buttwelding Ends for Pipe, Valves, Flanges and Fittings

ANSI B31.1.0	Power Piping
ANSI B46.1	Surface Texture
ANSI Y14	Drafting Manual

3.0 SYSTEM FUNCTIONS AND DESIGN FEATURES

3.1 Functions

The SGWCS shall be designed to:

- A. Receive heat from the secondary sodium loop by means of an evaporator and superheater to produce a stable supply of superheated steam.
- B. Provide proper water recirculation supply to the evaporator and steam flow to the superheater at normal and upset, emergency and faulted operations.
- C. Minimize the effects of a possible water to sodium side leak.
- D. Operate to meet the demand signal for monitoring stable operating conditions.

3.2 Design Features

3.2.1 Process Parameters

The SGWCS shall be designed to meet the following process parameters:

- A. The SGWCS shall be designed to meet maximum continuous rating (MCR) conditions listed in Table I:

TABLE I

Maximum Continuous Rating (100% Load) Design

Process Parameters

	<u>100% Load Design Conditions</u>
Steam Flow - Lb/Hr	95,390
Steam Drum Pressure - psig	2,700
Superheater Outlet Pressure-psig	2,500
Superheater Outlet Temperature - F	900
Feed Water Drum Inlet Temperature-F	460
Heat transfer rating - Mwt	26.6
(Partial listing-remainder to be provided later)	

- B. Physical Properties and Purity of Feed Water

The feedwater purity limits are given in Table II.

TABLE II

<u>Properties</u>	<u>PPB</u>
(1) Total dissolved solids	50 (max)
(2) Total silica	20

<u>Properties</u>	<u>PPB</u>
(3) Total iron	10
(4) Total copper	2
(5) Oxygen	5
(6) Hydrazine	10
(7) PH	9.2 - 9.4

C. Physical Properties and purity of recirculation water shall be maintained within the limits of the feedwater properties and purity.

3.2.2 System Configuration

The SGWCS shall be designed for installation in the SCTI facility having the following configurations:

- A. The system shall contain one (1) evaporator and one (1) superheater, one (1) steam drum, one (1) recirculating pump, isolation valves, and piping.
- B. There shall be no piping interconnections between the SGWCS and the SCTI System except for connecting the SGWCS to the SCTI at the terminal points.

3.2.3 System Flow Circulation

The SGWCS shall produce high pressure superheated steam in the following manner:

- A. Feedwater is fed to the steam drum and recirculated with the separated saturated water to the evaporators.
- B. The evaporator transfers the heat from the sodium to water to produce a mixture of saturated steam and water.
- C. The steam/water mixture enters the steam drum where it is separated into steam and saturated water.
- D. The saturated water is recirculated with incoming feed water; the saturated steam is passed through the superheaters where saturated steam is superheated to a temperature required for operating a steam turbine.

3.2.4 Evaporator Recirculation Requirements

- A. The Evaporator shall produce steam with an ample, predictable and stable circulation of water during normal operation, upset, emergency, and faulted operating conditions as defined in section 3.2.1 and appendix J.
- B. The recirculation system design shall have sufficient flexibility to permit:
 - (1) Adjustment of the recirculation ratio to the evaporators from 2 to 4 at 100% operating condition.

- (2) Increase total feedwater flow to 110% of design.
 - (3) The addition of an orifice pressure drop of 20 psi at CR of 4 and 100% operating conditions inlet of the evaporator to increase stability of operation.
- C. The steam drum shall produce separated steam quality of (to be provided later) to the superheater so that the superheater can operate to meet design steam temperature conditions.
 - D. The steam drum shall produce separated water that does not contain entrained steam.
 - E. The recirculation system design shall have sufficient piping flexibility to permit temperature changes from 80F to 690F without damage to piping and components.

3.2.5 Superheater Circulation Requirements

- A. The steam flow to the superheater is ample and predictable for normal operation over the load range and for upset, emergency and faulted operating conditions as defined in section 3.2.1 and Appendix J.
- B. Superheater circulation system shall have sufficient piping flexibility to permit temperature changes from 80F to 960F without damage to piping and components.

3.2.6 Structural Requirements

3.2.6.1 Design Objectives

Structural requirements of the circulation system shall be evaluated for adequacy of heat transfer and structural integrity for the design life time and under all the steady state and transient conditions.

Structural design shall consider the effect of pressure, thermal and cyclic loadings at normal and upset, emergency and faulted conditions.

The SGWCS shall be designed to withstand a full vacuum at 350°F.

3.2.6.2 Stress Limits

Allowable stress limits for all material used in the fabrication of the circulation system components and stress analysis procedures shall be in accordance with the applicable section of the ASME Boiler Pressure and Vessel Code (See section 2.2 and 2.3) and RDT Standards (See section 2.1)

3.2.6.3 Seismic Considerations

Static analysis shall be performed on Class 2 components.

A. Earthquake Zone 3

B. DBE Acceleration .2G Horizontal
 .1G Vertical
 acting sumultaneously

3.2.6.4 Vibration

The SGWCS and all its parts shall be designed to prevent damage or malfunction caused by flow - induced vibrations or by mechanical vibrations, such as pump vibrations, check valve hammer effects and impact loads caused by shipping. Vibration frequency less than (to be provided later) shall be prevented.

3.2.6.5 Differential Thermal Expansion

The SGWCS shall be designed to accommodate the differential thermal expansion for piping, tubing, and other parts within acceptable stress limits in accordance to applicable code defined in section 2.2 and 2.3.

3.2.6.6 Thermal Transients

Major pressure parts and piping components shall be analyzed for operating transients at normal and upset, emergency and faulted conditions using stress criteria of Section III of the ASME Boiler and Pressure Vessel Code.

Thermal transients for the SGWCS are provided in Appendix J.

3.2.6.7 Drum and Nozzle Loads

SGWCS drum and nozzles shall be designed to accommodate the piping loads for:

- A. Maximum design flexibility at normal and maximum upset operating conditions as defined in Appendix J.
- B. Operating transients at normal and upset, emergency and faulted conditions using criteria of Section III of the ASME Boiler and Pressure Vessel Code.

3.2.6.8 Sodium/Water Reaction

The SGWCS shall be designed to accommodate the shock forces caused by the quick isolation and dump of the steam/water side of the SGWCS following a water-to-sodium tube leak as defined in Appendix J.

3.2.6.9 Deformation and Deflections

Deformations and deflections from all causes, including inelastic behavior, creep and ratchetting, shall be determined for all components, their supports and appurtenances consistent with accepted stress and structural analysis. These deformations shall be evaluated by the specification issuer for their effect on:

- A. Functional requirements and assumed loading requirements.
- B. Interface requirements for supports and appurtenances.
- C. Safety and rupture.
- D. Acceptability of visible deformations in subsequent service inspections.

3.2.6.10 Corrosion Allowances

A corrosion allowance for all pressure boundaries of the SGWCS shall be (to be established later). The allowance includes compensation for the loss or degradation of material resulting from erosion, corrosion, intergranular penetration, chemical cleaning, and other environmental affects.

3.2.7 Materials of Construction Requirements

Materials to be used in the construction of the SGWCS shall be selected from the RDT materials standards listed in paragraph 2.1 of this specification. In addition to the requirements of these standards, the selected materials shall conform to the requirements of the applicable ASME Code. Any materials proposed for use in the construction of the SGWCS which are not in accordance with the above requirements will be approved by the Specification issuer. Materials used in the construction of the SGWCS shall be as follows: (to be provided later).

3.2.8 Required Instrumentation and Controls

- A. Process instrumentation and controls to monitor and control the steam generator for normal operation over the load range and for upset, emergency and faulted operating conditions are provided in Appendix D.
- B. The SGWCS shall include provision for periodic inspection and calibration of control instrumentation.
- C. The SGWCS shall include provision for removal and replacement of control instrumentation. Critical operating control instrumentation shall include redundancy, wherever possible, to minimize unscheduled shutdown of the unit.

3.2.9 Required Design Life

The SGWCS shall be designed to operate for the number, rate and duration of transients anticipated during a life period of 30 years as provided in Appendix J.

The test duration of the SGWCS shall be one year.

Components for which a 30 year life expectation cannot be reasonable assured shall be designed and installed to permit convenient replacement.

3.2.10 Design Safety Requirements

The design of the SGWCS shall meet all applicable, local, state and national safety requirements.

3.2.11 Required Maintenance and Operation Design

3.2.11.1 Maintenance Requirements

The following maintenance criteria shall apply to the design of the SGWCS:

A. The design shall permit access for removal, replacement and maintenance of system components.

B. The SGWCS shall be capable of complete drainage of water/steam except in the bayonet tubes of the steam generator.

- C. The SGWCS shall be designed for surveillance and inservice inspection of the following components. (To be provided later).

3.2.11.2 Preheat Operation Requirements

The SGWCS shall be heated from ambient temperature to a water/steam temperature of 350F using heated water flow circulation.

3.2.12 General Feature Requirements

- A. The SGWCS shall provide valves for quick isolation and dump of the water/steam side of the evaporator and superheater following a water-to-sodium leak.
- B. The SGWCS shall contain provision for relief of over-pressure caused by mal-operation.
- C. Insulation shall be provided in accordance with (to be provided later).

4.0 FABRICATION REQUIREMENTS

Fabrication of the SGWCS shall be in accordance with applicable RDT Standards and Codes listed in Section 2.0 - Applicable Documents.

5.0 INSTALLATION AND FIELD SERVICE REQUIREMENTS

Installation and field service requirements shall be in accordance with applicable RDT Standards and Codes listed in Section 2.0 - Applicable Documents.

6.0 REPORTS AND DOCUMENTATION REQUIREMENTS

Reports and documentation shall be in accordance with applicable RDT Standards and Codes listed in Section 2.0 - Applicable Documents.

7.0 DRAWING AND MANUAL REQUIREMENTS

Drawings shall be in accordance with RDT Standards and Codes listed in Section 2.0 - Applicable Documents.

8.0 QUALITY ASSURANCE REQUIREMENTS

Quality assurance requirements shall be in accordance with applicable RDT Standards and Codes listed in Section 2.0 - Applicable Documents.

9.0 PREPARATION FOR DELIVERY REQUIREMENTS

Preparation for delivery shall be in accordance with applicable RDT Standards and Codes listed in Section 2.0 - Applicable Documents.

10.0 GENERAL REQUIREMENTS

- A. Services of an engineer to supervise the SGWCS installation and to instruct personnel in operation and maintenance shall be provided.

11.0 DETAIL SPECIFICATIONS

The following information specifies the detail design requirements of the SGWCS for testing the 30 Mwt Sodium Steam Generator Test Model.

11.1 Detail System Arrangement

- A. A physical arrangement of the SGWCS is provided in layout drawings in Appendix C. (To be provided later).

The detail arrangement of the SGWCS consist of one (1) evaporator, one (1) superheater, one (1) steam drum and one (1) recirculating pump, valves and connecting piping. A summary of the component parts according to numbers, size and materials is provided in Appendix B.

11.2 Detail System Features

11.2.1 Detail Steam Generator Water/Steam Circulation System Description

The design of the SGWCS is shown in drawings (to be provided later) in Appendix C.

- A. Feedwater flow is brought to the 60" ID X () feet long steam drum through a 6-5/8" O.D. feedwater stop and check arrangement pipe section.
- B. The mixture leaves the drum through one (1) 8-5/8" O.D. downcomer and enters the recirculating pump.
- C. Recirculation water is discharged from the pump into one (1) 8-5/8" O.D. line containing a venturi flowmeter and a flow control valve for varying pressure drop to permit installation of orifices in the evaporator to increase flow ΔP .
- D. The water is fed to the evaporator through an 8-5/8" O.D. isolation valve.
- E. The steam/water mixture leaves the evaporator through a 8-5/8" O.D. discharge line containing an outlet isolation valve.
- F. The line connects to a 12-3/4" O.D. distribution header where the mixture is delivered uniformly to the drum by means of 6 - 5" O.D. tubes.
- G. The steam/water mixture enters a C-E standard controlled circulation 60" I.D. steam drum where the steam and saturated water are separated.

- H. The separated water in the drum mixes with the incoming feedwater, and the mixture begins the recirculation flow path described in items 11.2.1.A.
- I. The separated saturated steam leaves the drum by 3-5" O.D. tubes where it enters a 10-3/4" O.D. saturated steam collection header.
- J. The saturated steam proceeds from the collection header through 6-5/8" O.D. pipe into the superheater.
- K. The superheated steam discharges from the superheater, through a 8-5/8" O.D. pipe containing an isolation valve and connects to the SCTI facility desuperheater piping system.

11.2.2 SGWCS and Steam/Water Isolation and Dump

- A. The SGWCS shall be designed to isolate and dump the water or steam from an evaporator or superheater component in (time to be provided later) following a water-to-sodium leak.

NOTE: The water/steam isolation and dump system is connected to the SGWCS. However, the system is not included in this specification.

11.3 Detail System Performance Characteristics and General Features

11.3.1 Recirculation Loop Performance

- A. The water recirculation pump shall provide a constant, stable and predictable circulation ratio (C.R.) over a range of 2 to 4 at the 100% operating condition.
- B. The recirculation pump performance curve is provided in Appendix C, item (to be provided later). The pump is capable of producing a CR range of 2 to 4 at 100% load.
- C. A flow control valve is installed at the pump discharge to increase boiler water circulation and to add stability to the evaporator heated circuitry.
- D. The SGWCS uses a 60" I.D. conventional controlled circulation C-E steam drum with standard internals and associated system design of proven operational success at the same pressure and temperature conditions. The steam drum operation will:
 - (1) Provide steam quality of (to be provided later) and recirculation water that is free from carryunder of entrained generator steam.
 - (2) Steam and water mixtures entering the drum internals and recirculation water leaving the drum are uniformly distributed over the drum length to insure even water level and satisfactory drum internal operation.

11.4 Component Details

11.4.1 Piping

SGWCS pipe sizing and arrangement have been established by stress, hydraulic analysis and operational requirements. The SGWCS piping sizes limited fluid and steam velocities to less than:

- (1) 19. ft/sec for water
- (2) 25. ft/sec for water/steam mixture
- (3) 41. ft/sec for saturated steam
- (4) 120.ft/sec for superheated steam

A. Summary of the piping sizes is found in Appendix C.

B. Operating and design parameters for the piping are found in Appendix "B".

11.4.2 Steam Drum

See Appendix "G" for steam drum specification.

11.4.3 Recirculation Pump

See Appendix "H" for recirculating pumps specification.

11.4.4 Recirculating Pump Suction and Discharge Valves

See Appendix "I" for recirculating pump suction and discharge valve specification.

11.4.5 SGWCS Protection Against Over-Pressure Safety Valve

11.4.5.1 Evaporator and Superheater

Provision for protection of the sodium heated SGWCS components against over-pressure must be provided.

The safety relief valves shall be selected in accordance with the requirements of Section I of ASME Boiler & Pressure Vessel Code, Para. PG-67.2 of Section I.

The safety relief valves for the evaporator operating CR of 4 shall have relieving capacity of (to be provided later).

11.4.5.2 Steam Drum

The relieving capacity of the steam drums shall be calculated according to Appendix A-12 of Section I. This results in a relief capacity of (to be provided later) for the steam drum.

11.4.6 Steam/Water Isolation and Dump Valves

Steam/water isolation and dump valves are not covered by this specification.

11.4.7 Evaporator

Evaporator is not covered by this specification.

11.4.8 Superheater

Superheater is not covered by this specification.

11.5 Instrumentation and Controls

Process instrumentation, logic and controls for operation of the SGWCS in the SCTI shall consists of the following:

A. Instrumentation is to be provided to measure and record SGWCS process parameters and equipment operation such as flows, pressures, temperatures, drum level and steam conductivity.

(1) A detail list of instrumentation to be provided for the SGWCS is included (to be provided later) in Appendix D.

(2) Process parameters are included in Appendix "C".

(3) Back up instrument sensors are to be provided when such equipment is inaccessible for convenient maintenance.

B. SGWCS controls will perform the following functions but are not covered by this specification:

- (1) Steam drum water level control to hold water level within the required limits.
- (2) Steam generator controls such as feedwater flow, steam flow, superheater outlet pressure, superheater outlet temperature control.

11.6 Maintenance

A. Provisions to perform routine maintenance activities during shutdown shall be provided. The SGWCS will be designed for maintenance activities in the following order of preference:

- (1) Adjust and repair equipment in place.
- (2) Replace components with spare unit (repair the disabled unit).

B. General Comments are:

- (1) Items, such as motors, valves, actuators, sensors, etc. are to be designed and installed to permit inspection, adjustment and repair.
- (2) Sufficient space, handling equipment, and accessibility are to be provided to minimize maintenance activities.
- (3) Critical operating items are to have redundancy to prevent unscheduled shutdown of the system.

- (4) Provision to move large components from the building to a maintenance facility will be provided for such items as circulating pump motors, steam drum, etc.

(Partial listing - additional listing to be added).

Appendix A
References
(to be provided later)

Appendix B
Parameter List
(to be provided later)

Appendix C

Drawings

(to be provided later)

Appendix D
Instrument List
(to be provided later)

Appendix E
Valve List
(to be provided later)

Appendix F

Equipment List

(to be provided later)

Appendix G
SPECIFICATION
FOR
STEAM DRUM
(To Be Provided Later)

Appendix H
SPECIFICATION
FOR
RECIRCULATING PUMP
(To Be Provided Later)

Appendix J
SPECIFICATION
FOR
RECIRCULATING PUMP
SUCTION AND DISCHARGE
VALVE
(To Be Provided Later)

Appendix K
DEMONSTRATION PLANT STEAM
GENERATOR RDT STANDARD
SPECIFICATION SECTION 3.6,
OPERATING CONDITIONS
(To Be Provided Later)

APPENDIX C

PRELIMINARY TEST SPECIFICATION

FOR

30 MWt TEST MODEL

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STEAM GENERATOR TESTING IN THE
SODIUM COMPONENTS TEST INSTALLATION (SCTI)

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JANUARY 1973

COMBUSTION ENGINEERING, INC.

Nuclear Components Department

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5. 1. 1. 5 Steady State Operation

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5. 1. 1. 7 Steady State Heat Transfer

5. 1. 1. 8 Normal Power Transients

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5. 1. 1. 10 Once-Through Operation

5.2 Data

5.2.1 Test Procedures

5.2.2 Test Documentation

5.2.3 Certificates of Test Waivers

4.6.2.6 5% Power Increase Transient

4.6.2.7 10% Power Step Change

4.6.3 Upset and Emergency Transients

4.6.3.1 Plant Trip

4.6.3.2 Loss of Primary Sodium Flow

4.6.3.3 Secondary Sodium Flow Up -Ramp

4.6.3.4 Turbine Trip

4.6.3.5 Loss of Feedwater Flow

4.6.3.6 Loss of Recirculating Pump

4.6.3.7 Feedwater Flow Up-Ramp

4.6.3.8 Loss of Secondary Sodium Flow

4.6.4 Once-Through Operation and Heat Transfer Tests

4.6.4.1 Low Flow Stability

4.6.4.2 Steady State Heat Transfer Tests

4.6.4.3 Transient Operation

4.6.5 Associated Systems Testing

5. Notes and Data

5.1 Notes

5.1.1 Test Objectives

5.1.1.1 Strain Gauge

5.1.1.2 Preheat

5.1.1.3 Vibration

5.1.1.4 Startup - Shutdown

**STEAM GENERATOR TESTING IN THE SODIUM
COMPONENT TEST INSTALLATION**

1. Scope - This specification establishes the requirements for testing of a recirculating*sodium heated bayonet tube steam generator. The testing requirements are such as to utilize, to the extent possible, the present capability of the Sodium Components Test Installation (SCTI) to test the steam generator for the operating modes and conditions expected for those that will be installed in the first LMFBR Demonstration Plant. Certain tests for the steam generator auxiliary systems may also be inserted later. These auxiliary systems consist of:

- Steam - water circulating system
- Steam - water isolation and dump system
- Gas pressure control and sodium level control system
- Leak detection system
- Steam generator instrumentation and control
- Sodium/water reaction pressure relief system

A sodium-water reaction relief system will be utilized in the steam generator installation at the SCTI, but it is not currently planned to test this system.

The SCTI equipment does not include a sodium isolation and rapid dump system that will be required in the Demonstration Plant.

Detailed system design descriptions of these associated systems are contained in other documents.

*Certain tests may be inserted to operate the steam generator at once through conditions. This will require drum by-pass piping and valves.

Normal operating limits for the steam generator are:

- Constant steam pressure and temperature of (later) psig and 900°F respectively at a feedwater flow rate of 38,500 lbs/hr, (40% load).

- Constant steam pressure and temperature of 2500 psig and 900°F respectively at a feedwater flow rate of 96,500 lbs/hr at 100% load. These limits are within SCTI capability.

Certain tests will be performed at 110% of full load flow of the secondary sodium through the steam generator. This requires a sodium flow rate of 1.12×10^6 lbs/hr and is also within SCTI capability.

2. Documents

2.1 Applicable Documents - The following documents of the issue date shown form a part of this specification to the extent specified in sections (later) and (later) of this document. In the event of a conflict between the documents referenced herein and other detail content of this specification, the detail content of RDT E4-16T specification including the MODIFICATIONS and ORDERING DATA listed below shall be considered a superceding requirement.

Specifications

RDT E4-16T, Sodium Heated Steam Generator

CE-EP-7670-1 Modifications to RDT E4-16T

CE-EP-7670-2 Ordering Data, Sodium Heated Steam Generator

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CE Manual CE-EP-7670-6

- Shipping Handling and Storage
- Maintenance
- Hydrostatic Testing

RDT Standards - as applicable

Drawings

Steam Generator General Arrangement (Side Elevation)
Steam Generator General Arrangement (Front Elevation)
Steam Generator General Arrangement (Sections)
Superheater Arrangement
Evaporator Arrangement
Steam Drum and Piping Arrangement
Internal Thermocouple Installation
External Instrumentation Installation
Steam Generator Shipping Arrangement

3. Requirements

3.1 Test Program Objectives - The objectives of the test program for the steam generator and auxiliary systems are as follows:

- Within the limits of the SCTI capability, verify that the steam generator meets or exceeds the performance requirements specified in RDT E4-16T for sodium heated steam generators, and, if the steam generator does not meet these requirements, to define any performance deficiencies.
- Within the limits of present instrumentation technology, evaluate the

mechanical design capability of the steam generator to function as required in a LMFBR system.

- Assist in reducing any uncertainties pertaining to the operating characteristics of the steam generators; and establish various operating procedures.
- Enhance the technological state-of-the-art for LMFBR steam generators.

3.1.1 Temperature and Flow Conditions - The steam generator can be tested in the SCTI for all steady state design conditions specified in the design specification. Some of the design transient conditions for the demonstration plant steam generators cannot be exactly duplicated in the SCTI when testing the steam generators. The transient rates in the SCTI shall be as close as practicable to the design transients.

3.1.2 Cyclic Conditions - The actual number of cycles (preheat, low flow stability, startup-shutdown, normal power transients, and upset and emergency transients) expected during the 30-year life of the Demonstration Plant steam generators will not be duplicated in the test program. In lieu of the 30-year cyclic conditions, the test program shall limit the number of cycles to those which will provide consistent experimental data. Within the limits of the experimental data, an analytical projection of the capability of the steam generator to meet the expected cyclic requirements will be made by Combustion Engineering. Steady-state tests shall be repeated a sufficient number of times to provide the data required to verify the steam generating capability of the unit.

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3.2 Estimated Performance - The estimated performance characteristics for the Combustion Engineering Steam Generator shall be as indicated in the following figures and tables. The estimated performance shall be demonstrated by the tests of Section 4, and shall provide verification of compliance with the requirements of RDT E4-16T, Modifications to RDT E4-16T, CE-EP-7670-1, and the Ordering Data, CE-EP-7670-2.

Estimated Performance

<u>Condition</u>	<u>Reference</u>
Startup - Shutdown	Figures 1, &3
Steady State Operations	Figures 4, &5
Normal Power Transients	
2%/min Power Ramp	Figure 6
5%/min Power Ramp	Figure 9
10% stop change	Figure 14
Upset and Emergency Transients	
Plant Trip	Figures 15 & 16
Loss of Primary Flow with Secondary Sodium Flow Continuing	Figure 21
Secondary Sodium Flow Up-Ramp with Feedwater Flow Constant at 25%	Figure 18 & 24
Turbine Trip	Figures 27 & 28
Loss of Feedwater Flow with Secondary Sodium Flow Continuing at 100%	Figure 31
Loss of recirculating pump	Figure 34
Circulation Ratio (CR) Tests	Table 12

3.3 Pretest Requirements - Prior to conducting any test, test procedures shall be available and the required instrument calibrations shall be accomplished and certified as per 3.3.3

3.3.1 Test Procedure - Test procedures shall be prepared by LMEC and approved by Combustion Engineering prior to conducting any test (refer to 6.2.1).

3.3.2 Data Recording - The data to be recorded and the frequency of recording, are indicated in Tables 1 through 6 . Any additional data may be recorded as deemed applicable. The experimental data shall be recorded so as to be available for future reference.

Immediately after an unplanned steam generator or SCTI plant trip, all experimental measurements shall be recorded at an initial rate of one or more per second. When temperature changes of 100F/hr. or less are reached, the recording rate may be reduced to one or more per five minutes and when temperature changes of 50 F/hr or less are reached, the recording rate may be reduced to one or more per ten minutes.

3.3.3 Data Validation - A data validation plan for all the test instrumentation shall be prepared and submitted to the Combustion Engineering representative for review.

3.3.3.1 Instrument Calibration Traceability - Instrument calibration curves shall be traceable to NBS. The data accuracy shall be that specified in 3.3.3.2.

3.3.3.2 Instrument Calibration - The absolute inaccuracy of the instrumentation shall be less than the following:

3.3.3.2 Instrument Calibration continued**Absolute Inaccuracy**

Temperature	± 15 F
H ₂ O Pressure	± 25 psi
Na Pressure	± 5 psi
H ₂ O Flow	± 0.5 percent of full flow
Na flow	± 5 percent of full flow
Accelerometers	$\pm .05$ g
Strains	± 100 micro inches plus 10 percent of strain level
Steam Quality	± 1 percent

3.4 Post Test Requirements - At the completion of any test, the experimental data shall be validated as instructed in the Data Validation Plan (Ref. 3.3.3) and stored.

3.4.1 Data Handling - The test data shall be removed from the recorders, identified, dated, and reviewed for discrepancies by LMEC. The discrepancies shall be noted. The data shall be corrected for instrument errors and calibration and reduced to engineering units so as to be applicable for test documentation (refer to 6.2.2).

3.4.2 Data Storage - All recorded data shall be stored in a safe manner so as to provide easy access for future reference.

3.5 Precautions - In the installation and testing stages of the steam generators test program, the following precautions shall be taken. (Note: A separate document

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3.5 Precautions continued

will cover requirements on post test removal).

3.5.1 Test Constraints - The test constraints as specified in Table (later) shall not be exceeded at any time except when required by specified test conditions. Should a constraint be exceeded, corrective action shall be taken immediately to bring the temperature distributions within the specified constraints. The Combustion Engineering representative shall be notified prior to continuing the test.

The on-line monitoring equipment shall display the most critical constraints for each test as indicated in Table 11.

3.5.2 Safety - In addition to normal SCTI protective systems provisions (including hydrogen monitoring devices), safety oriented precautions to be included in the test procedures and facilities where applicable shall include the following:

1. A pressure relief system capable of handling the reaction products resulting from a sodium water reaction shall be provided downstream of the rupture disc located on the shell side of both evaporator and superheater modules. A nitrogen atmosphere with an oxygen content of two percent or less shall be maintained downstream of the rupture disc located on the shell side of the modules. A reaction products separation tank with a pressure relief to the atmosphere shall also be provided. No operation of the steam generator shall be allowed if the oxygen content in the relief system exceeds the 2% value.

2. Means are provided on the secondary sodium side of the steam generator for continuous venting of the cover gas which is monitored for hydrogen.

The steam generator shall immediately be shut down and the water side pressure reduced to (later) psig if hydrogen in the secondary sodium system cover gas is detected that is increasing at a rate faster than (later) ppm in six minutes. *

3. During application of the various ramps (refer to 4.6) deviations in excess of ± 10 percent in flow, ± 10 percent in pressure and ± 20 F in temperature from the required value at any instant of time shall result in the ramp being stopped, the system conditions returned to the initial values slowly and the ramp reapplied.

4. In the event of component or control system malfunction which results in flow, pressure, or temperature deviations above the maximum design conditions given in RDT E4-16T Ordering Data, immediate effort shall be made to minimize the thermal and pressure shocks to the evaporator while initiating a rapid load reduction or shutdown procedure.

5. If a malfunction occurs for which there is no guidance directive, the Combustion Engineering representative shall be notified immediately. Based on the nature of the event and the operating history up to the time of the malfunction, the Combustion Engineering representative will determine (with the concurrence of LMEC) whether to continue or to terminate the testing.

*This requirement may be modified depending upon whether operating experience indicates frequent false leak indications due to temperature swings.

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3.5.3 Test Article Handling , Storage, Cleaning - Specific storage, cleaning and shipping requirements for the steam generator modules are specified in CE-EP-7670-6. The test procedures shall conform with these requirements where applicable. Installation of the steam generator in the SCTI shall be done in accordance with a Combustion Engineering approved procedure.

In the event excessive fouling on the tube side of the evaporator occurs and cleaning is required, the cleaning shall be done in accordance with a Combustion Engineering approved cleaning procedure.

3.5.4 Data Acquisition System Unavailability - In the event the data acquisition system is unavailable for data recording, the plant shall be maintained in a steady state condition. No changes shall be made during the steady state condition. If the data acquisition system is unavailable for more than one hour, the Combustion Engineering representative shall be notified.

3.6 Test Fluids

3.6.1 Sodium - The composition of the sodium shall be in conformance with RDT E4-16T Ordering Data with normal plugging temperature of 300⁰F or less.

3.6.2 Feedwater - The feedwater chemistry and expected impurity levels shall not exceed those specified in RDT E4-16T Ordering Data.

3.6.3 Cover Gases - The cover gases, Argon and Nitrogen, shall conform to the requirements specified in RDT E4-16T Ordering Data.

4. Quality Assurance Provisions

4.1 Test Input Conditions

1. Strain gauge tests	See para. 4.6.1.1
2. Vibration	See Para. 4.6.1.3
3. Preheat	See Para. 4.6.1.2
4. Low flow stability	See Para. 4.6.4.1
5. Startup-Shutdown	Figures 1, 2, 3
6. Steady-state operation	Table 8
7. Steady-state heat transfer	Table 9
8. Normal power transients	Figures 7, 8, 10, 11, 12, 13
9. Upset and emergency transients	Figures 19, 20, 22, 23, 25, 26, 29, 30, 32, 33

4.2 Test Sequence - Testing of the evaporator shall be as agreed to between Combustion Engineering and LMEC.

4.3 Test Tolerances - During a test the steady-state set-points (test input conditions) shall agree with the values specified in 4.1 within the following tolerance values:

Flows	± 1 percent
Temperatures	$\pm 5F$
Pressures	± 10 psi

In the event of deviations greater than the specified values, corrective action shall be taken to re-establish the specified value before proceeding with the test.

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4.4 Incomplete Tests - Failure to complete any test or portion thereof, shall require concurrency of the Combustion Engineering representative prior to proceeding with other tests.

4.5 Witnesses - At the completion of each test, the test data and log book will be signed off by LMEC person in charge, and a witness.

4.6 Test Methods - The following tests shall be conducted to verify compliance with the requirements of 3.2

Unless otherwise noted under the specific test, each test shall be repeated two or more times or until consistent experimental data is defined as agreement of the experimental results of two or more runs within the same error band as the input data.

4.6.1 Mechanical and Pre-operational Testing

4.6.1.1 Strain Gauge Tests - The initial conditions for the strain gauge test shall be with the steam generator modules void of sodium and water and at ambient temperature. All strain gauge readings shall be zeroed to provide a base reading. Water shall be at the purity level of RDT ordering data prior to entering the steam generator. The steam generator shall be filled with the water at ambient temperature. The water temperature shall be increased to 160 plus or minus 5 F at a rate compatible with the constraints specified in 4.6.1.2. When the water purity and temperature requirements are met, the water shall be pressurized to 2500 psig and readings from all strain gauges shall be recorded (Table 6).

The water pressure shall then be reduced to zero psig and readings from all

strain gauges shall be recorded (Table 6). (This up-down cycle is to stabilize the strain gauges.) When the stabilization cycle has been completed, the tube side water pressure shall be increased to 500 psig and readings from all strain gauges shall be recorded (Table 6). The water pressure shall then be increased to 1000 psig, 2000 psig, and 2500 psig with readings from all strain gauges being recorded at each pressure (Table 6). The pressure shall then be reduced to 500 psig and a check of the strain gauge readings shall be recorded.

The feedwater temperature shall then be increased to 350 F in preparation for filling with sodium.

With the evaporator sodium and feedwater temperature at 350 F, sodium flow of 486,000 lb/hr at an inlet pressure of 30 to 50 psig, feedwater flow of 6500 to 38,500 lb/hr., and water outlet pressure of 600 psig, the water flow shall be reduced to zero, the water outlet pressure increased to 800 psig and the evaporator gradually brought to isothermal conditions at 500 F by increasing the sodium temperature. With the evaporator isothermal at 500 F the tube side pressure shall be increased to 1000 psig, and strain gauge readings shall be recorded (Table 6). The tube side water pressure shall then be increased to 2000 psig and 2500 psig with the strain gauge readings being recorded at each pressure (Table 6). The tube side water pressure shall then be reduced to 1000 psig with strain gauge readings being recorded.

4.6.1.2 Preheat - The initial condition for the preheat test shall be with the steam generator modules void of sodium and water and at ambient temperature. The water temperature may be raised up to 150 F for cleanup in the bypass loop. Water shall be at the purity level specified in RDT E4-16T prior to entering the steam generator. The modules shall be filled with the water at ambient temperature. The water temperature shall be increased at a maximum rate of 100 F per hour. The water flow rate may be varied as required for SCTI control stability between 6500 and 38,500 lb/hr. The heat up rate shall be maintained until an on-line monitored constraint limit is approached.* The water temperature shall be held constant until the restricting temperatures are partially diminished. The preheat temperature program shall then be reapplied until an on-line monitored constraint limit is approached. The water temperature shall be held constant until the restricting temperatures are partially diminished. This alternate preheating and constant feedwater temperature soaking shall be applied until the feedwater temperature has been raised to 350 F. Concurrently, the steam lines shall be heated by saturated steam at the same temperature as the water with the source of the steam being either the preheat boiler or the flash tank. Preheating of parts of the steam generator sodium shells will be aided by electrical heaters on the exterior surfaces of the shells. Preheating of the feedwater system, steam generator and flash tank shall be continued until the

*The degree of approach shall be chosen so as to prevent an overshoot. The approach limit should be set by SCTI on the basis of past operating experience, the on-line rate of change, and the control response of the SCTI.

feedwater system, steam generator, flash tank, and steam lines are stabilized at 350 F. Water and steam flows shall be continued until the desired water purity is obtained. While the feedwater system, steam generator, flash tank, and steam system are being preheated, the sodium lines shall be electrically preheated to 350 F.

Water at 350 F shall then be pressurized to 600 psig while maintaining a water flow of 6500 to 38,500 lb/hr. Feedwater flows, temperatures, and pressures shall be monitored throughout the test (see Tables 1 to 5).

4.6.1.3 Vibration Test - Test runs shall be made with sodium flows of zero, 5, 10, 20, 40, 50, 60, 80, 100, and 110 percent of rated flow (1.02×10^6 lb/hr). Sodium temperature shall be 350 F* flowing on the shell side, with no water or steam in the tubes. Accelerometer readings (see Table 5) shall be taken at the various flow rates while maintaining the flow rate constant over a ten minute period. Various tubes will be selected for testing in this test series. Accelerometers will be placed inside the bayonet tubes at various tube positions and at different elevations in each of the selected tubes. The smaller diameter insulator and bayonet tubes will be removed during these tests.

At the conclusion of the vibration test, one or two of the external accelerometers will be selected to be monitored during the remainder of

*Deviations from this sodium temperature are permissible provided requirements of 3.3.3.2 are satisfied.

the test program, (see Table 5).

4.6.2 Operational and Heat Transfer Testing

4.6.2.1 Startup - Shutdown - The startup and shutdown tests can be combined as one test to facilitate and minimize testing time.

The initial conditions for the startup test shall be with the steam generator, sodium and water at 350°F, sodium flow of 486,000 lb/hr , feedwater flow of 6500 to 38,500 lb/hr and water pressure of 600 psig. The secondary sodium and water temperatures and water pressure shall then be varied with time until the temperatures and pressures are at normal values for 40 percent feedwater flow (see Figures 1, 2 & 3).

The 40 percent feedwater flow condition shall be maintained for two hours or until steady-state conditions prevail, then the shutdown procedure shall be initiated.

The shutdown procedure shall be initiated by varying the secondary sodium and water temperatures and pressures with time as shown in Figures 2 and 3. The completion of the shutdown procedure shall be when the steam generator, sodium, and water are stabilized at 350°F, the sodium flow is 486,000 lb/hr, feedwater flow is 6500 to 38,500 lb/hr, and the water pressure is 600 psig. The temperature at 350°F may be maintained by the pumps and electrical heaters on the sodium system.

During the startup - shutdown tests, experimental data shall be recorded in accordance with Tables 1 - 5 inclusive.

The estimated performance of the steam generator operating under startup - shutdown conditions is shown in Figure 1.

4.6.2.1 continued

In the event temperature changes larger than 100°F in 1/2 hour below 900°F and 50°F in 1/2 hour above 900°F are imposed on the steam generator, corrective action shall be taken, all the data recorded (see Tables 1 through 5 inclusive), and a malfunction report prepared. In the event temperature changes larger than twice these values are imposed on the steam generator, the test shall be discontinued, the steam generator returned to isothermal condition at 350°F with a minimum of temperature transients, all the data recorded (see Tables 1 through 5 inclusive), and the Combustion Engineering representative notified before continuing the tests. A malfunction report shall then be prepared.

4.6.2.2 Steady-State Operations - The test shall be initiated with the steam generator sodium inlet temperatures and flow rate (Table 8), feedwater inlet temperatures and flows, and outlet steam pressures and temperature at normal values for a feedwater flow of 38,500 lb/hr (see Table 8). The feedwater flows, sodium flow, inlet temperatures, steam outlet pressures, and steam outlet temperature shall be varied in accordance with Table 8. At each value of feedwater flow, steady-state shall be established and the required data recorded (see Tables 1 through 5 inclusive).

The predicted performance of the steam generator operating at various feedwater flow rates in Table 8 is shown in Figures 4 and 5.

4.6.2.3 Test to Optimize Circulation Ratio (CR) - The thermal sizing for the evaporator portion of the steam generator is based upon a circulation ratio (CR) of 3.5. Data for boiling annular flow of the type found in a bayonet tube evaporator is scarce and at best, questionable. In order to provide reasonable assurance that departure from nucleate boiling (DNB) does not occur in the evaporator, a relatively high value for CR was chosen. The lowest circulation ratio that is compatible with all the other operating characteristics is to be desired since the initial capital costs for the steam generator and associated hardware such as pumps, piping, steam drum, etc. will be reduced. In addition, the pumping power of the recirculation pumps over the life of an LMFBR plant may be significantly reduced. These tests shall be initiated with the steam generator sodium and feedwater temperatures and flow rates and exiting steam pressure and circulation ratio at the values for 100% power level. (See Table 11)

Conditions at 100% Power Level

Sodium flow rate	1.02×10^6 lbs/hr.
Sodium inlet temperature	960°F
Sodium outlet temperature	673°F
Feedwater flow rate	397,000 lb/hr.
Feedwater temperature	460°F
Steam outlet temperature	900°F
Steam outlet pressure	2500 psia
Circulation ratio	3.5

From this operating condition of 100% power, the circulation ratio shall then

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be reduced to 3.25. After steady state conditions are reached the temperatures and pressures listed in Table 11 are to be recorded. The reduction in CR from the initial value of 3.5 to a new value of 3.25 should be accompanied by an increase in superheated steam outlet pressure and a decrease in evaporator sodium outlet temperature.

Repeat these tests at the following values for the circulation ratios:

3.5 (initial), 3.25, 3.0, 2.75, 2.5, 2.25, 2.0 and 1.75

Steam outlet pressure will continue to increase and sodium outlet temperature decrease with further reduction in CR until a point is reached where the trend reverse and go in the other direction. The CR at which the highest steam pressure accompanied by the lowest sodium outlet temperature occurs will be the optimum point provided all other requirements are met.

4.6.2.4 Steady-State Heat Transfer Tests - The test shall be initiated with the steam generators sodium and water inlet temperature and flow rates and exiting steam pressure at the initial values given in Table 9. Steady-state shall be established and the experimental data recorded, see Tables 1 to 5 inclusive. For conditions shown in Table 9, the sodium flow shall be held constant and the feedwater flow then varied as indicated. When all the runs varying feedwater flow at one sodium flow rate have been completed, a new steady-state condition, at the next sodium flow rate shall be established in accordance with Table 9, and the test repeated for each sodium flow rate.

To provide additional data for use in interpreting test results, a heat loss determination shall be made. Initial conditions for the heat determination will consist of sodium in the shells at $450 \pm 15^{\circ}\text{F}$, and no water or steam in the unit.

From this condition, temperatures will be permitted to decrease to $300 \pm 10^{\circ}\text{F}$ with the secondary pump de-energized. Data shall be recorded as specified in Table 3.

4.6.2.5 Three Percent Per Minute Power Ramp - The initial conditions for the three percent per minute power ramp test shall be with the Steam Generator generating 38,500 lb/hr of steam at steadystate. Feedwater and sodium flows and temperatures and steam outlet pressure shall then be varied in accordance with Figures 7 and 8. Steady-state with the steam generator generating 96,500 lb/hr of steam shall be established before the down ramp is applied and the evaporator returned to a steam generation rate of 38,500 lb/hr.

Steady-state shall be established at a steam generation rate of 38,500 lb/hr which will then complete one power swing at a power ramp of three percent per minute. During the three percent per minute power ramp test the required temperatures, flow rates, pressures, steam quality and accelerometers shall be recorded in accordance with Tables 1 through 5. The estimated performance of the steam generator operating under conditions of a three percent per minute power ramp is shown in Figure 6.

4.6.2.6 Five Percent Per Minute Power Ramp - The test for the power swing at five percent per minute power ramp shall be similar to the three percent per minute power ramp except that Figures 10 and 11 shall be adhered to for the input conditions. The estimated performance of the steam generator operating under conditions of a five percent per minute power ramp is shown in Figure 9.

4.6.2.7 Ten Percent Step Change - The initial conditions for the step change tests shall be with the steam generator generating 96,500 lb/hr of steam at steady-state. Feedwater and sodium flows and temperatures and steam outlet pressure shall then be reduced in accordance with Figures 12 and 13. Steady-state shall be established at 86,700 lb/hr of steam and then the feedwater and sodium flows and temperatures and steam outlet pressure shall be increased in accordance with Figures 12 and 13. Steady-state shall be established at 96,500 lb/hr of steam which will complete one step change cycle. During the cycle, the required temperatures, flow rates, pressures, steam quality and accelerometers will be recorded, see Tables 1 to 5 inclusive.

The estimated performance of the steam generator operating under conditions of a 10% step up or down in power is shown in figure 14.

4.6.3 Upset and Emergency Transients - The upset and emergency transients which the steam generator has been designed for have been summarized into the following tests.

4.6.3.1 Simulated Plant Trip - The initial conditions for the plant trip test shall be with the steam generator generating 96,500 lb/hr of steam (Ref. Table 8) at steady-state conditions. Sodium flow shall then be reduced linearly from 1.02×10^6 lb/hr to $.051 \times 10^6$ lb/hr in ten seconds, with the sodium inlet temperature held at 960°F. Concurrently the feedwater flow shall be reduced to about (later) lb/hr in ten seconds to maintain a constant sodium outlet temperature of (later) . The superheater steam outlet pressure will be held constant at 2500 psig, and the feedwater temperature maintained at 460°F.

4.6.3.1 continued

The conditions of $.051 \times 10^6$ lb/hr of sodium flow, feedwater temperature of 460°F , evaporator exit sodium temperature of 673°F and superheater inlet sodium temperature of 960°F shall then be maintained until steady-state conditions are obtained.

The various flow and temperature ramps that are to be applied to the steam generator to simulate the plant trip are shown in Figures 17 and 18.

During the simulated plant trip test, the required temperatures, flow rates, pressures, steam quality and accelerometers shall be recorded, see Tables 1 to 5.

The estimated performance of the steam generator operating under the conditions imposed by the plant trip test is shown in Figures 15 and 16.

4.6.3.2 Simulated Loss of Primary Sodium Flow with Secondary Sodium Flow Continuing - The initial conditions for the loss of primary sodium flow with secondary sodium flow continuing test shall be with the steam generator operating at partial power, with feedwater entering at (later) and sufficient pressure to produce superheated steam leaving at (later) psig and The sodium inlet temperature shall be (later) and the sodium outlet temperature shall be (later) . The sodium flow and feedwater flow shall be varied to obtain these temperatures (see Table 8).

After a steady state condition has been established, the loss of primary sodium flow with the secondary sodium flow continuing test shall be initiated by (1) decreasing the steam generator sodium inlet temperature at a rate of 18 F/sec.

4. 6. 3. 2 continued

(later) to (later)*; (2) decreasing the feedwater flow from (later) lb/hr to (later) lb/hr in about seven seconds, and (3) maintaining the feedwater inlet temperature at (later).

The conditions of (later) lb/hr feedwater flow, secondary sodium flow constant, sodium inlet temperature of (later) and feedwater inlet temperature at (later) shall then be maintained until steady state conditions are obtained.

The various flows and temperature ramps to be applied to the steam generator simulate the loss of primary sodium flow with secondary sodium flow continuing test are shown on Figures 19 and 20.

During the loss of primary sodium flow with secondary sodium flow continuing test, the required temperatures, flow rates, pressures, steam quality, and accelerometers shall be recorded, see Tables 1 to 5 inclusive.

The estimated performance of the steam generator operating under the conditions imposed by the loss of primary sodium flow with secondary sodium flow continuing test is shown in Figure 21.

4. 6. 3. 3 Simulated Secondary Flow Up-Ramp with Feedwater Flow Held Constant at (later) lb/hr (tentative) - The initial conditions for the secondary sodium flow up-ramp with the feedwater flow held constant at (later) lb/hr test shall be with the evaporator generating (later) lb/hr of steam at steady state (see Table 8). The secondary sodium flow shall be maintained constant at (later) lb/hr, the steam generator sodium inlet temperature shall be reduced from

*Sodium inlet temperature shall not be allowed to fall below 10°F above water saturation temperature.

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4.6.3.2 continued

(later) to (later) in seven seconds, the steam outlet pressure shall be maintained constant at (later) psig and the feedwater inlet temperature shall be maintained at

When the steam generator inlet temperature of (later) is obtained, the temperature shall be maintained until steady state conditions are reached.

The various flows and temperatures that are to be applied to the steam generator to simulate the secondary sodium flow up-ramp with the feedwater flow held constant at (later) lb/hr are shown in Figures 22 and 23.

During the secondary sodium flow up-ramp with the feedwater held constant at (later) lb/hr, the required temperatures, flow rates, pressures, steam quality, and accelerometers will be recorded, see Tables 1 to 5 inclusive.

The estimated performance of the steam generator operating under the conditions imposed by the secondary sodium flow up-ramp with feedwater flow held constant test, is shown in Figure 24.

4.6.3.4 Simulated Turbine Trip - The initial conditions for the turbine trip test shall be with the unit operating at 100% power, with 98,500 lb/hr of feedwater entering at 460°F and sufficient pressure to produce superheated steam leaving at 2500 psig and 900°F. The sodium inlet temperature shall be (later) and the sodium outlet temperature shall be (later). The sodium flow shall be varied to obtain these temperatures, see Table 8 and Figures 4 and 5.

The test for the turbine trip condition shall be initiated by closing the steam outlet regulating valve and allowing the safety valves to release the excess steam. This simulates closing of the turbine stop valve. Simulation

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4.6.3.4 continued

of the opening of the steam dump valve shall be by regulation of the steam outlet valve as soon as the simulated turbine trip has been completed. Concurrently to the closing of the steam outlet regulating valve, the sodium flow shall be reduced from (later) lb/hr. to (later) lb/hr. in three minutes, the sodium inlet temperature shall be maintained at (later) and the feedwater inlet temperature maintained at (later). The sodium outlet temperature shall be maintained at (later) by variation of the feedwater flow.

The steam outlet pressure shall be reestablished at (later) psig by the steam outlet regulating valve. At the end of the three-minute period, the sodium flow shall then be increased from (later) to (later) lb/hr in (later) minutes. Sodium inlet and outlet temperatures and feedwater temperature shall be maintained constant at (later), (later), and (later) respectively. The steam outlet pressure shall be maintained constant at (later) psig. When a sodium flow of (later) lb/hr is reached, the up-ramp shall be stopped and steady state conditions established.

The various flow and temperature ramps that are to be applied to the steam generator to simulate the turbine trip are shown in Figures 25 and 26.

During the simulated turbine trip power down-ramp and up-ramp, the temperatures, flow rates, pressures, steam quality, and accelerometers shall be recorded, see Tables 1 to 5 inclusive.

The estimated performance of the steam generator operation, under the conditions imposed by the turbine trip test is shown in Figures 27 and 28.

4. 6. 3. 5 Simulated Loss of Feedwater Flow

(Later)

Figure 23 - 24 Input Conditions

Figure 25 Estimated Performance

4. 6. 3. 6 Simulated Loss of Recirculating Pump

(Later)

Figures 26 - 27 Input Conditions

Figure 28 Estimated Performance

4. 6. 3. 7 Simulated Feedwater Flow Up-Ramp

Tentative (Later)

4. 6. 3. 8 Simulated Loss of Secondary Sodium Flow

Tentative (Later)

4. 6. 4 Once Through Operation and Heat Transfer Tests - The following tests are proposed for operation of the CE bayonet tube steam generator at once-through conditions. These tests will advance the state of the art pertaining to steam generators of this general type.

These tests will probably be performed at the end of the test series since minor modifications to the steam generator systems will be required. These modifications will consist of isolating the recirculating loop from the steam generator evaporator and superheater modules and rerouting the feedwater supply directly to the evaporator inlet nozzle.

Although it might not be absolutely necessary, it might be desirable to install piping directly from the evaporator module to the superheater module,

4.6.4 continued

thus bypassing the steam drum and reducing pressure drops and heat loss.

4.6.4.1 Low Flow Stability - This test shall be initiated with the sodium flow, sodium inlet temperature, water side pressure, feedwater temperature, and feedwater flow being established at the maximum values shown in Table 7. The feedwater flow shall be reduced, either in small steps or a slow ramp ($15,000 \text{ lb/hr}^2$) and the water side ΔP and exit steam thermocouples (Tables 1B and 4) monitored for any indication of water flow instability*.

*Instability shall be defined as any one or more of the following:

1. When any one or more of the exiting steam thermocouples (TC- to TC- incl.) oscillates individually in temperature by more than $\pm 15^\circ\text{F}$. Oscillations attributable to fluctuations in SCTI input conditions shall not be regarded as instability.
2. When any one or more of the exiting steam thermocouples (TC- to TC incl.) read saturation temperature with the remaining exiting steam thermocouples reading superheated steam temperatures of not less than 10°F superheat.
3. When the water side pressure drop across the evaporator module varies by more than $\pm 15\%$ of the average value. Oscillations attributable to fluctuations in SCTI input condition shall not be regarded as instability.
4. When a "jump" type phenomena in which large apparent changes in tube side heat transfer regime occur as a result of minor perturbations of SCTI "steady-state" input conditions. An example of such a heat transfer and flow regime jump is a sudden large (e.g., five feet or more) change in film boiling length. Such jumps may be inferred from changes in sodium temperature profiles along the length of the unit.
5. When the evaporator outlet steam quality fluctuates by more than $\pm 20\%$ of the nominal value. An example would be large slugs of water leaving the evaporator rather than a homogeneous mixture.

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4.6.4.1 continued

When the lowest value of feedwater flow desired is obtained with no instabilities noted, new initial conditions shall be established at temperature change rates not in excess of 100°F in 1/2 hour. Should water side flow instabilities be detected, the conditions necessary to initiate water side flow instability shall be confirmed, recorded (see Tables 1 through 9), stability re-established, and then new initial conditions based on steady-state values shall be established for the next test.

Additional tests may be required depending upon what, if any, instabilities are found.

4.6.4.2 Steady State Heat Transfer Tests

Later

(Not extensive)

4.6.4.3 Transient Operation

Later

(Not extensive)

4.6.5 Associated Systems Testing

Later

5. Notes and Data5.1 Notes

5.1.1 Test Objectives - The test program (refer to Section 4) will verify the design by proof testing and if the experimental data obtained in the tests are available in time, improvements in the design of the steam generators for the

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5. 1. 1 continued

LMFBR Demonstration Plant could be made. In addition, the test program will assist in reducing uncertainties relative to steam generator operating characteristics.

5. 1. 1. 1 Strain Gauge - The strain gauge test (refer to 4. 6. 1. 1) will assist in reducing the uncertainties relative to stress levels in the steam generator structure. The test may show that the results obtained in the structural analysis were too conservative and future designs may benefit by the use of thinner structural members.

5. 1. 1. 2 Preheat - The preheat test (refer to 4. 6. 1. 2) will assist in reducing the uncertainties associates with the preheat operating procedures and the design of the steam generators to withstand the number of preheat phases expected during a 30 year period. The test may show that the preheat rates can be increased over the values now specified.

5. 1. 1. 3 Vibration - The vibration test (refer to 4. 6. 1. 3) will primarily insure that no excessive vibrations are resulting in the steam generator installation in the SCTI when the steam generator is subjected to the sodium flows of interest. In addition, the uncertainty as to tube wear at the tube supports may be reduced by visual inspection after completion of all the sodium tests.

5. 1. 1. 4 Startup - Shutdown - The startup - shutdown test (refer to 4. 6. 2. 1) will assist in reducing the uncertainties associated with the design of the steam generators to withstand the number of startup and shutdown cycles expected during a 30-year plant life. The major uncertainties are 1) the stability of the water side flow at low flow rates and low pressures;

5. 1. 1. 4 continued

2) control at low sodium flows; 3) the variations in tubesheet-to-shell ΔT 's, and 4) the transient temperature gradients within the steam generator structure.

The test information may indicate that the startup and shutdown rates may be increased over the values now specified.

5. 1. 1. 5 Steady-State Operation - The steady-state operation test data (refer to 4. 6. 2. 2) will assist in reducing the uncertainties relative to operation of the steam generator at part load conditions. These uncertainties are the water flow stability and distribution at low loads and the resulting temperature differences or stresses. In addition, the data obtained for the 100% load condition will indicate the degree of conservatism (if any) in the calculated value of the over-all heat transfer coefficient. If the experimental data indicated a higher value was justified, the steam generator surface area may be reduced, resulting in a capital cost savings.

5. 1. 1. 6 Test to Optimize Circulation Ratio - These circulation ratio variation tests (refer to 4. 6. 2. 3) will assist in optimizing the operational characteristics of the steam generator and could result in substantial initial hardware cost savings and operational savings over the life of an LMFBR plant.

5. 1. 1. 7 Steady-State Heat Transfer - The steady-state heat transfer test (refer to 4. 6. 2. 4) will assist in reducing the uncertainties relative to the tube side heat transfer coefficients for the water side convection, nucleate boiling, film boiling and superheat sections. A reduction of these uncertainties could result in reduction of the required heat transfer surface area in subsequent units.

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5. 1. 1. 8 Normal Power Transients - The normal power transient test data (refer to 4. 6. 2. 5, 4. 6. 2. 6 and 4. 6. 2. 7) will assist in reducing the uncertainty associated with design and operation of the steam generator to withstand the number of normal power transients expected over a 30-year plant life. The major uncertainties are 1) the response time of the steam generator to perturbations in the sodium and feedwater temperatures, flows and pressures; 2) water side flow stability during the transients; 3) control of outlet steam temperature and pressure during the transient; 4) the temperature gradients in the steam generator structure; and 5) water carryover (if any) from the steam drum. The test data may indicate that the normal power transient rates can be increased and that the design can be simplified.

5. 1. 1. 9 Upset and Emergency Transients - The upset and emergency transient test data (refer to 4. 6. 3) will assist in reducing the uncertainty associated with design and operation of the steam generator to withstand the upset and emergency transients chosen as representatives of what might possibly be applied to the steam generators over a 30-year plant life. The major uncertainties are 1) the response time of the evaporator to perturbations in the sodium and feedwater temperatures, flows and pressures; 2) water side flow stability during the transients; 3) control of outlet steam temperature and pressure during the transients; 4) water carryover from the steam drum; 5) the variation in tubesheet to shell ΔT 's and the temperature gradients in the evaporator structure; and 6) ability to withstand thermal stresses. The technical data may indicate that the design can be simplified.

5.1.1.10 Once-Through Operation and Heat Transfer Tests - The once through operational and heat transfer tests will assist in reducing the uncertainties associated with design and operation of this type of steam generator for LMFBR application.

The major uncertainties are 1) low load stability; 2) operation limitations, if any, that are peculiar to the design; and 3) Control of steam outlet pressures and temperatures during transients.

5.2 Data

5.2.1 Test Procedures - Detailed test procedures for each test Section 4 shall be prepared and submitted to the CE Representative for review. No testing shall be conducted until CE has accepted the procedure.

5.2.2 Test Documentation - Test documentation shall be prepared by LMEC for each test specified in Section 4.6. Test documentation shall include the following:

Reference to applicable test procedure

Reference to test instrument validations

Summary of reduced experimental data, corrected for instrument calibration, for each test conducted. The reduced experimental data shall be in the form of curves and tables in engineering units.

Plots of data made during tests to ensure data taken is valid.

Record of test failures / malfunctions and plant trips.

Test data log sheets.

Summary highlights of the operational history showing the chronological events pertaining to the steam generator test shall be recorded and forwarded

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5.2.2 continued

to CE on a weekly basis.

5.2.3 Certificates of Test Waivers - In the event that any test cannot be performed as specified, a certificate of waiver of test completion shall be obtained before proceeding with the next test. The certificate of waiver of test completion shall 1) specify the reason for not being able to complete the test; 2) contain a description of the degree to which the test was performed; and 3) show approval of CE Representative.

5.2.4 Data Forms - The forms for recording test data, safety precautions, and observations shall be developed by LMEC. The data forms shall be submitted to the CE Representative for review and shall become a part of the Test Procedure (refer to 5.2.1).

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