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JUL 29 1968

SUPERCritical TECHNOLOGY PROGRAM

FINAL REPORT

May, 1968

AT(30-1)-3374

RESEARCH AND DEVELOPMENT REPORT

PREPARED FOR THE N.Y. OPERATIONS OFFICE
U. S. ATOMIC ENERGY COMMISSION

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ABSTRACT

This is the Final Topical Report summarizing work performed under AEC Contract AT(30-1)-3374 for the period April 6, 1964 through April 15, 1965.

The objectives of this program were to:

1. Build and install a supercritical water-cooled, in-pile, fuel testing loop.
2. Demonstrate the feasibility of collapsed clad fuel elements in a reactor environment, cooled by supercritical water.
3. Evaluate the design of the fuel elements by post-irradiation examination.
4. Evaluate loop performance by analyzing operating data.

Two fuel assemblies manufactured by different methods (pellets and vibratory compaction) were to be tested. Fuel rods containing pellets were clad with Incoloy 800, while those which are vibratory compacted and swaged were clad with 16 Cr - 20 Ni stainless steel.

An existing loop design and large number of loop components previously purchased by Westinghouse have been turned over to the AEC under the terms of the contract. The design of the loop is complete and the remainder of the components have been purchased under the contract. Fuel assembly and pressure tube designs have been completed. Two pressure tubes and the first fuel assembly have been fabricated.

The program was suspended on April 15, 1965 and the contract was terminated on November 3, 1965 for the convenience of the government.

PART I - PROGRAM OBJECTIVES

1.0 INTRODUCTION

This is the Final Topical Report on research and development work under AEC Contract AT(30-1)-3374 for the period from April 6, 1964 through April 15, 1965. The program consisted of nearly completing the design and fabrication of a supercritical pressure water cooled, in-pile loop. Two fuel assemblies were to be tested in a pressure tube inserted into the Saxton reactor. The irradiated fuel would have been examined at the Westinghouse Post Irradiation Facility, and the loop performance evaluated.

The designs were largely completed under a Westinghouse-funded program prior to the contract period. In addition, most of the loop components and several parts of the pressure tube and fuel assemblies were purchased under this program.

The following reports have been issued under the contract:

<u>WAPD Report No.</u>	<u>Title</u>
None Required	Monthly Progress Letters for the months of April, May, July, August, October, November 1964; January, February 1965.
WCAP-2626	Work Programs for the period April 6, 1964 to September 3-, 1964.
WCAP-3374-1	First Quarterly Progress Report, April to June 1964.
WCAP-3374-2	Second Quarterly Progress Report, July to September 1964.
WCAP-3374-3	Work Programs for the Period October 1, 1964 to March 31, 1965.
WCAP-3374-4	Third Quarterly Progress Report, October-December 1964.
WCAP-3374-5	Fourth Quarterly Progress Report, January-March 1965.
WCAP-3374-6	Work Program for the Period April 1, 1965 to November 30, 1965.
WCAP-3374-7	Evaluation of Zircaloy-Stainless Steel Metallurgically Bonded Joints for the Supercritical Technology Program.

2.0 VALUE OF SUPERCRITICAL TECHNOLOGY

In the United States, the electric utility industry has attained a high state of technical and economic development. The cost of power has been steadily reduced while load growth has doubled almost every ten years. Improved steam conditions have made possible higher efficiency, lower fuel cost and lower component costs for large stations. The application of supercritical pressure steam, with its excellent heat transfer and heat transport properties, has played a leading role in this development.

Because of these superior properties, interest in supercritical water as a reactor coolant has been widespread. Westinghouse^(1,2) and other organizations^(3,4) in the United States have conducted design studies. Interest has also been shown in the USSR⁽⁵⁾, United Kingdom⁽⁶⁾, Germany and other countries.

2.1 SUPERCRITICAL FLUID AS A REACTOR COOLANT

General

The use of supercritical fluid (water) above the critical pressure and temperature (3206 psia, 705°F) as a reactor coolant offers many specific advantages because of its unique physical and nuclear properties. Supercritical fluid has excellent heat transfer and heat transport characteristics; does not exhibit a change of phase; and has considerable flexibility with regard to hydrogen density and neutron slowing down effects. The use of heavy water or mixtures of heavy and light water provides further flexibility in neutron interaction properties.

Wide application of water and steam as a working fluid and coolant has resulted in a technical background of water chemistry and related technology which is not exceeded by any other single compound. This fund of technical data is available for application in supercritical reactors yet to be developed.

Specific Heat

High performance in heat transfer and heat transport depends in large degree on the specific heat of the coolant (Figure 1). From this curve, it is apparent that supercritical fluid has a higher average specific heat over the range 100°F to 1000°F than any other reactor coolant. For example, the heat transported through a temperature rise of 30°F in supercritical pressure fluid near the critical temperature is as much as ten times as great as that transported by liquid sodium with an equal temperature rise. The core enthalpy rise can vary from 150 to 1000 Btu per pound, depending on the particular nuclear system and mechanical arrangement under development. As a direct result, the amount of fluid to be pumped is greatly reduced, with an attendant reduction in loop equipment size, piping, pumps, etc. Thermal transients and resulting thermal stresses are correspondingly reduced.

Density and Spectral Hardness

Supercritical fluid offers reactor designers a wide latitude in temperature, heat pickup and neutron spectral hardness unavailable in most other reactor coolants. The neutron energy can be maintained at the thermal level by limiting the outlet temperature or by use of a separate moderator. It can be adjusted in the intermediate range by selection of the fuel lattice pitch and coolant temperature, and can be fully hardened into a fast spectrum by using low density steam or heavy water mixtures.

Heat Transfer

Heat transfer in supercritical pressure fluids is accomplished primarily through convection, with the coefficient strongly dependent on the mass flow rate. At pressures above 3206 psia, water behaves essentially as a single phase fluid. No distinct steam phase is formed to create the problems of two phase flow and heat transfer. Convection heat transfer coefficients are high, and the heat-carrying capability is very large due to the high value of specific heat over much of its temperature range.

Figure I-1
Specific Heats of Coolants

2.2 APPLICATIONS AND CONCEPTS

Possible Applications

Possible applications of the unique properties of supercritical fluid include: (1) large central power stations; (2) small compact power systems; and (3) marine propulsion plants.

In 1963, Westinghouse completed a design study for a 1000 MWe central station plant under AEC Contract AT(30-1)-2948. The concept selected was the Supercritical Once-Through Tube Reactor (SCOTT-R) ---- a direct cycle, pressure tube, thermal reactor with either graphite⁽¹⁾ or D₂O moderator.

This concept is only representative of a whole new family of reactors cooled with supercritical fluid, which show potential for achieving low capital costs while maintaining acceptably low fuel cycle costs. Conversion ratios that appear feasible range from those typical with present day water reactors (0.5 to 0.7) to breeders (BR up to 1.25). Technology developed during the construction and operation of a supercritical pressure closed cycle converter would be directly applicable to more advanced systems such as breeders and/or direct cycle systems. Possible concepts using supercritical water as a coolant are described below:

Supercritical Closed Cycle Water Reactors (SC-PWR)

This concept (Figure 2) is similar to present day closed cycle water reactors. It incorporates an open lattice, single pass core operating in a thermal neutron spectrum, with shim control provided by chemical additions to the coolant.

Supercritical Mixed Spectrum Reactor

This concept (Figure 3) can be either a closed or direct cycle system. It incorporates at least two coolant passes in the core. Inlet coolant passing through the outer region of the core provides

Figure I-2
Closed Cycle Supercritical Pressure
Water Reactor

Figure I-3

Supercritical Pressure Mixed Spectrum Reactor

sufficient moderation to produce an intermediate neutron spectrum in this region. Higher temperature, lower density coolant in the central part of the core results in a fast neutron spectrum.

Supercritical Fast Breeder

The use of very low density supercritical fluid at conditions above the pseudo-critical temperature (approximately 722°F at 3500 psia) with a high fuel-to-coolant fraction results in a fast neutron spectrum. Such a system is possible using a modified Loeffler cycle. The breeding gain may be enhanced through the use of light water - heavy water mixture as a reactor coolant.

Small Air Transportable Plants

Direct cycle, supercritical pressure reactors appear attractive for small, air-transportable power plants. Westinghouse studies have shown that such a concept offers a significant advance in efficiency and simplicity, plus a significant reduction in size, weight, and cost over the first generation of portable closed cycle water reactors.

Marine Propulsion Plants

Lower weights, sizes and circulation rates plus higher efficiencies make supercritical reactors attractive for advanced marine propulsion plants. Either direct or closed cycle systems might be considered.

2.3 ECONOMIC POTENTIAL

The supercritical central station concepts described above could offer plant cost reductions of between \$8 and \$20 per installed kw over present day water reactor systems for plants in the 800-1000 MW sizes. These savings accrue through the following factors:

1. The enthalpy rise of the coolant passing through the core can be increased by a factor of 2 to 10 beyond those that are now common, thus significantly reducing the cost of pumps and piping.
2. The average coolant temperature level can be increased with a supercritical fluid coolant. The higher temperatures can be used in closed cycle systems to increase the steam generator temperature difference for heat transfer, thus reducing its size and cost.
3. The higher steam temperatures and pressures possible at the turbine inlet for both closed cycle and direct cycle systems will improve cycle efficiency and significantly reduce the cost of the turbine generator plant. Higher efficiencies will also make possible better fuel utilization and lower fuel cycle costs.
4. The absence of DNB limits at supercritical pressure makes higher core power densities possible, resulting in a smaller and lighter reactor vessel despite the higher operating pressures.
5. The contained energy of a supercritical reactor system is less than half that of present systems, making possible a major reduction in containment cost.

3.0 FEASIBILITY PROBLEMS

3.1 GENERAL

Continuing conventional plant development provides many of the components and systems required for supercritical reactors. The principal reactor development problems thus lie in the areas of fuel development and coolant chemistry, the major areas towards which the Supercritical Technology Program is directed.

Fuel Development

The behavior of the fuel cladding constitutes the most important single area in determining the economic and technical feasibility of all supercritical reactor concepts.

The major obstacle to establishing fuel feasibility lies in the area of mechanical thermal strain cycling. Unless pressure balancing^{*} should prove feasible, the high coolant pressure would collapse the clad intimately on the fuel at operating conditions. Thus, it would be subjected to strain due to differences in thermal expansion that occur with every change in power level. In the case of a breeder, average burnups of at least 40,000 MWD/MTU or more are required to achieve competitive fuel cycle costs. Fuel swelling at high burnups would impose additional strains on the cladding which, coupled with radiation effects, could limit fuel life and the economic potential of a breeder.

Simultaneously with meeting cyclic operating conditions, the fuel clad must be able to operate at temperatures in the range of 1100 to 1300°F without experiencing appreciable corrosion and must retain sufficient ductility in the irradiated condition. Materials such as Incoloy 800 and a Westinghouse modified 16 Cr-20 Ni iron alloy show promise in meeting these requirements, provided adequate water chemistry conditions can be maintained.

Water Chemistry and Corrosion

To date, the behavior of supercritical fluid in the presence of ionizing radiation has not been investigated, thus it is not currently known what oxygen concentration levels may be present in the supercritical reactor. Radiolytic decomposition of the coolant will certainly occur and some level of oxygen concentration will be present.

* Pressure balancing would involve pressurization of the fuel rod internally with gas to partially balance the external pressure forces during operation.

Since the presence of both higher temperatures and pressures tend to assist natural recombination of the hydrogen and oxygen products, it is anticipated that the oxygen levels will be appreciably less than those of the typical boiling water reactor (20 ppm). However, they will probably be in excess of the conditions encountered in conventional fossil fuel units -- in the order of 50 ppb. The presence and level of oxygen in the coolant is a critical factor in the formation of crud or scale on the fuel element clad since it can greatly accelerate the corrosion rates and apparently plays a contributory role in stress corrosion phenomena. Therefore, the development of methods for control and suppression of oxygen in the coolant may constitute a key feasibility item.

In the case of a closed cycle system, radiolysis might be suppressed and a reducing condition achieved by maintaining a suitable dissolved hydrogen concentration. An NH_3 addition might also maintain the pH of the coolant at levels conducive to low deposition rates.

In a direct cycle system, suppression of radiolysis and maintenance of reducing conditions can probably be achieved by continuous injection of ammonia or hydrazine.

Another aspect of water chemistry control essential to the supercritical concept is that of dissolved solids in the coolant. If appreciable solids are present, they will deposit on the fuel element surface, creating an insulating layer of crud. Such crud can have the effect of increasing clad temperatures by several hundred degrees, making clad failure highly probable. Conventional fossil fuel units have been able to circumvent deposition problems by the use of ultra-pure (less than 50 ppb) feedwater. Purity of this level can foreseeably be achieved by conventional demineralization techniques, although the actual requirements for the more severe reactor environment remain to be established by in-pile experience.

The presence of dissolved chlorides, solids and oxygen in the reactor coolant would certainly enhance the chances of stress corrosion attack on the fuel clad. The cladding materials listed previously are highly resistant to the stress corrosion mechanism. It will probably be desirable to use materials of this type, in any event, to protect the reactor clad during those periods of uncontrolled water chemistry which can occur in any operating plant.

3.2 STATUS OF THE TECHNOLOGY

In undertaking the development program on supercritical technology, an effort was made to identify those problems most closely associated with technical and economic feasibility. The following received primary activity: performance of the fluid and fuel under simulated reactor conditions; heat transfer; corrosion studies; and fuel development. This work benefited greatly from preliminary studies in the AEC superheat program, particularly with regard to materials selection and fabrication methods for fuel.

Status of Heat Transfer

Westinghouse has conducted experimental programs in the area of heat transfer at the required reactor conditions. The Westinghouse program, sponsored by the AEC on Contract AT(30-1)-2948, investigated mass flows in the range of 2 million pounds per hour per square foot and heat flux in excess of one million Btu per hour square foot. The supercritical pressure correlation developed from this work allowed, for the first time, accurate prediction of heat transfer coefficients over the entire range of reactor temperatures with a single correlation. (7,8)

The work noted in reference (7) has also made some effort to identify the "whistle" phenomena in supercritical heat transfer. The phenomena, thought to arise from non-equilibrium thermal conditions existing in the coolant, could cause excessive surface temperature conditions if the heat flux is increased above $850,000 \text{ Btu/hr-ft}^2$ near the pseudo-critical temperature.

This work in supercritical heat transfer forms a sound base for preliminary studies of the heat transfer performance of supercritical cooled water reactors. More detailed mockups of actual fuel assemblies, as well as parallel channel flow distribution, oscillation and stability will undoubtedly be devised for any supercritical reactor concepts scheduled for construction.

Status of Corrosion

Corrosion studies were undertaken by Westinghouse under AEC Contract AT(30-1)-2948 to determine the performance of high nickel stainless steel fuel cladding in supercritical fluid having high oxygen and chloride contents. This is the only work reported thus far⁽⁹⁾ on corrosion of supercritical fluids at anticipated or accelerated reactor conditions. The results are indicated below:

1. Chloride stress corrosion does not appear to constitute a significant problem. Although severe corrosion was observed, it could in no way be associated with the chloride content of the system.
2. The corrosion rate observed during these stringent and abnormal water chemistry conditions was found to be excessive. However, such conditions differ significantly from those expected in a reactor.
3. A buildup of scale deposit on the fuel was noted. This buildup apparently arose from two sources:
 - a. Deposition of crud from the loop cooling water, particularly near the transition temperature of the bulk fluid; and
 - b. Oxidation and corrosion of the fuel clad sample.

These results are in direct contrast to those obtained in a typical heat transfer test section where the supercritical fluid oxygen level was maintained at below 0.1 ppm. Thus, it would appear that the use

of supercritical fluid as a reactor coolant might depend on the low oxygen levels in the system. Although there is no experimental evidence on the behavior of supercritical fluid in the presence of ionizing radiation, it can be predicted that there would be very little or no net oxygen produced in the system.

The suppression of radiolytic-produced oxygen by adding hydrazine or ammonia to the boiler feed water is also being investigated. Quantitative suppression has resulted from the use of hydrazine in the Beloyarsk USSR boiling superheat reactor.⁽⁵⁾ UKAEA has reported similar results in boiling superheat loops in reactors at Chalk River. It is thus reasonable to anticipate that the corrosion problem in supercritical water reactors can be satisfactorily handled by water chemistry control currently predicted in conventional plants, with the possible requirement for the addition of modest quantities of oxygen-suppressing chemicals.

Status of Fuel Development

No fuel elements have as yet been tested at supercritical conditions. Because of the large loads imposed on the cladding by supercritical fluid, it is anticipated it will operate in the plastic range. Such clad has been developed to some degree through the numerous superheat and gas cooled reactor programs.

Work conducted on the AEC superheat program, indicates that it is possible to design plastically deformed clad for satisfactory operation within a given range of cycles. Fuel swelling and fission product gas release are detail engineering problems and can be dealt with satisfactorily in the mechanical design of the fuel pin.

The Supercritical Technology Program incorporates first actual test of nuclear fuel and supercritical steam conditions and performed in a special supercritical loop installed in the experimental pressurized

water reactor at Saxton, Pennsylvania. The feasibility of all the supercritical concepts previously discussed would eventually rest on the demonstrated satisfactory performance of the fuel.

4.0 OBJECTIVES OF THE SUPERCRITICAL TECHNOLOGY PROGRAM

The overall objectives of the in-pile test program in the Saxton reactor are as follows:

1. Complete the design, fabrication, and erection of an in-pile, supercritical water, fuel testing loop and fuel assemblies.
2. Test collapsed clad fuel assemblies and a pressure tube under supercritical water environmental conditions.
3. Evaluate the fuel assemblies by means of post-irradiation examination to provide necessary information for improved design methods and material selection.
4. Establish experimentally the corrosion and mass transport behavior of fuel and pressure tube assemblies, and the effect of loop chemistry and irradiation on corrosion.
5. Analyze loop and fuel assembly performance.

The first phase of the Supercritical Technology Program was devoted to completing the design of an in-pile loop which was largely completed under a Westinghouse-funded research and development program. The balance of the components were purchased under the present program. The components were assembled into pre-fabricated packages, and installed in the Saxton reactor. This experimental reactor, located at Saxton, Pennsylvania, is owned and operated by the Saxton Nuclear Experimental Corporation (SNEC) which conducts a reactor technology research and development program in cooperation with the Westinghouse Electric Corporation.

The second phase of the program involved the design, component procurement, and fabrication of two pressure tubes and two fuel assemblies. It was planned to insert a pressure tube into Saxton reactor. The fuel assemblies would then be tested in the pressure tubes. These and certain other key components were designed under the Westinghouse-funded program, previously mentioned. The reference design of the pressure tube incorporated a metallurgically bonded, Zircaloy 4 to stainless steel, transition joint. Six of these joints were purchased under the Westinghouse-funded program. Their evaluation was completed under the present program. Three joints were destroyed in testing, and three were damaged during cold drawing. To meet schedule requirements, an all-stainless steel pressure tube would have been used in the reactor.

The fuel was manufactured in the form of rods, with seven rods per assembly, by two processes and from two materials. The first fuel assembly consisted of rods of UO_2 pellets, 21% enriched, loaded into Incoloy-800 tubes. The fuel rods for the second assembly was manufactured by vibratory compaction of fused UO_2 powder (also 21% enriched) into tubes of a Westinghouse alloy, 16 Cr - 20 Ni stainless steel. The tubes were then swaged to about 91% theoretical fuel density.

The fuel assemblies were to be tested, under reactor operating conditions, at 3600 psia pressure and at temperatures up to 1000°F. The test period was to last from 6 to 12 weeks, the total test period for both assemblies not exceeding 18 weeks. Following irradiation, the fuel assemblies would have been shipped to the Westinghouse Post-Irradiation Facility located at Waltz Mill, Pennsylvania. The fuel assemblies would then be examined visually and with instruments. Dimensional checks would be made and compared with the pre-irradiation measurements. Sections of cladding would be tested to determine the effect of irradiation and cycling on the physical properties of the material.

The final phase of the program was an analysis of the post-irradiation data on the fuel and cladding. The mechanical design would be analyzed to evaluate its performance and to develop information which will be useful in future designs. The loop performance would be analyzed with respect to system operation and chemical performance. Since this was the first in-pile test of collapsed clad under reactor environmental conditions with supercritical water coolant, the results obtained in the program would be an important bench-mark in future investigations.

PART II - LOOP DESIGN AND CONSTRUCTION

1.0 FUNCTION

The In-Pile Supercritical Loop supplies water to the experimental pressure tube installed in the Saxton Reactor at the required inlet conditions, to cool the experimental fuel assembly.

2.0 GENERAL DESCRIPTION

The Supercritical Loop is shown on the Process Flow Diagram, Figure 1 and the Sampling Equipment Diagram Figure 2. All system equipment is located in the vapor container with the exception of portions of the ammonia injection system and the low pressure water sampling systems.

The Supercritical Loop includes the following equipment:

- a. Two high-head loop pumps
- b. One standby high-head pump
- c. One interchanger (regenerative heat exchanger)
- d. One electric pre-heater
- e. One pressure tube
- f. One high-pressure cooler
- g. One low-pressure cooler
- h. One deaerator
- i. Two condensate pumps
- j. One demineralizer
- k. Two filters, 5 and 25 micron
- l. Three specimen holders
- m. One accumulator
- n. One coolant reservoir with refill tank
- o. One reservoir gas cylinder
- p. One gas compressor
- q. Two air compressors, 12 and 72 cfm with air dryer, oil absorber and filter
- r. One vacuum pump package, containing a vacuum pump, a pump seal water reservoir and a pump seal water cooler

FIGURE II-2
 SAMPLE SYSTEM FLOW DIAGRAM

- s. One catalytic recombiner package, including recombiner condensing heat exchanger, and diluent steam generator.
- t. One head tank
- u. One feed tank
- v. One emergency condenser
- w. One reactor bleed cooler
- x. Ammonia injection pumps and associated tanks
- y. Pump leakage return pump and associated tank
- z. Three sample coolers
- aa. Three sample ion exchangers
- bb. Associated piping, valves and instrumentation

The Loop is furnished with makeup water, component cooling water, and service water from the reactor plant supplies. In addition, portions of the reactor plant sampling system, pressure relief system, purification system and radioactive waste disposal facility are used during Supercritical Loop operation.

Since the experimental fuel assembly utilizes the reactor core as a source of neutrons, the Supercritical Loop operates only when the reactor is operated at power. While the pressure tube containing the fuel assembly is mounted in the reactor vessel, there is no direct contact between Supercritical Loop coolant and reactor coolant streams. The Supercritical Loop operating pressures will normally exceed reactor operating pressure.

The Loop can operate at both subcritical and supercritical pressures. However, since the initial experimental program is restricted to supercritical pressure operation, the equipment necessary for subcritical pressure conditions only has not been installed for the first series of tests.

During operation, cold clean, degassed coolant is supplied to the suction of a loop pump which delivers the desired flow at the pressure required by the particular experiment. The coolant flows through the

shell side of the interchanger and thence into the heater. It leaves the heater at a specified temperature and passes through the pressure tube and fuel assembly. Upon leaving the pressure tube, the coolant flows through the interchanger tube side and the high-pressure cooler, where its temperature is further reduced. Next the coolant passes through a pressure-reducing valve and into the low-pressure cooler where additional temperature and pressure reductions take place. The cooled, low-pressure water is discharged through a spray nozzle into the deaerator, where essentially all radiolytic and fission gases are removed. The condensate pumps, taking suction from the deaerator, pump the degassed water through the mixed-bed demineralizer and the filter to the loop pump suction.

Regulation of loop pump pressure fluctuations is provided by the accumulator which is connected to the pump discharge line. Loop flow is controlled by returning a portion of the pump discharge to the pump suction through a bypass valve.

Water makeup and net positive suction head for the loop pump are provided by the head tank. The feed tank is connected parallel to the head tank and is used for decontamination. A continual injection of ammonia is maintained at the inlet to the main loop pumps during all reactor operation.

Non-condensable gases are removed from the Loop in the deaerator. These gases consist mainly of hydrogen and nitrogen produced by radiolytic and thermal decomposition of ammonia plus radiolytic hydrogen and oxygen and possibly small quantities of fission gases. Since the deaerator operates below atmospheric pressure, a water-sealed vacuum pump is used to remove the gases and discharge the mixture into the catalytic recombiner. A steam generator supplies diluent steam to this mixture prior to entering the recombiner in order to keep the hydrogen concentration below the explosive range. Essentially all the steam in the recombiner effluent is condensed in the recombiner condenser, which discharges the condensate to the vacuum pump seal water reservoir. In addition, an air stream is bled into the catalytic recombiner to provide sufficient oxygen for recombination of the excess hydrogen generated through ammonia decomposition.

The residue of non-condensable gases flows to the radioactive waste disposal facility. An automatic control maintains a preset level in the seal water reservoir by draining excess water to the deaerator. The seal water circuit contains a cooler to remove the heat added to the water in the vacuum pump.

Crud samples can be taken continuously from three points in the Loop, immediately upstream of corrosion specimen holders 1 and 2 and downstream of specimen holder 3. Each sample stream flows through a cooler, then through a pressure-reducing device into a sample ion-exchanger. Impurities in the stream are retained by the ion-exchange resin, and the effluent is returned to the Loop at the deaerator. Periodically, additional samples are taken upstream and downstream of the supercritical loop demineralizer and between the pressure reducing valve and the low pressure cooler. Since these are cold, low-pressure streams, they are routed to the plant sampling system, outside the vapor container, where normal sampling techniques may be used.

In order to prevent excessive temperature gradients in the reactor vessel head near the penetration used for the Supercritical Loop pressure tube, a stream of reactor coolant is bled through the annulus between the pressure tube and penetration nozzle. This bleed stream cools the nozzle to the same temperature as the surrounding metal. The stream flows into a cooling coil immersed in the storage well water, through a pressure letdown valve and into the Saxton purification system. The bleed stream is entirely independent of the Supercritical Loop coolant.

2.1 LAYOUT

Most of the Supercritical Loop equipment is located in the primary compartment. The loop pumps, demineralizer, filters, accumulator, coolant reservoir, gas cylinder and compressors are located in the auxiliary compartment. The pressure tube, emergency condenser and reactor bleed cooler are in the storage well while the feed tank is on the operating floor, above the storage well. When the reactor is subcritical, personnel access to the operating floor, primary compartment and auxiliary compartment is permitted.

Local shielding is provided for the demineralizer, the filters, the sample ion exchangers and the in-line radiation monitor downstream of the condensate pumps. The demineralizer is located near the reactor plant demineralizers to permit use of the existing resin handling lines and equipment. Valves located behind shielding have extension handles to permit operation during resin sampling or replacement.

The condensate pumps are located below the deaerator to meet NPSH requirements. Similarly the head tank and feed tank are elevated to meet loop pump NPSH requirements and to permit filling the Loop by gravity flow.

The emergency condenser is located above the pressure tube to provide sufficient thermal circulation head and to reduce piping flow resistances. The coolant reservoir and its associated piping are located to reduce delay time for injection of coolant into the Loop, within the limits of available space.

Wherever possible, several related components, complete with valves and connecting piping, are grouped as a package to simplify installation and conserve space.

The Table below gives the major equipment packages and the components contained in each package.

<u>Package</u>	<u>Components Included</u>
A	Interchanger, High-Pressure Cooler, Low-Pressure Cooler, Specimen Holders 1 and 2.
B	Deaerator, Vacuum Pump Package, Recombiner Package.
C	Coolant Reservoir, Gas Cylinder, Gas Compressor, Gas Bottle, Air Compressors, Air Dryer.

Package

Components Included

D

Loop Pumps #1 and 2, Standby Pump, Accumulator.

E

Heater

3.0 DESCRIPTION OF EQUIPMENT

3.1 COMPONENTS

3.1.1 Loop Pumps

Each loop pump can supply coolant at the required pressure to the fuel assembly. Each pump is a two-speed, triplex, positive-displacement type, with integral check valves. All parts in contact with the coolant are austenitic stainless steel or equivalent corrosion-resistance material. A leakoff system is provided to collect and monitor coolant leakage. The primary seal leakage is piped to a hold-up tank, and then pumped at required intervals to the loop deaerator. This system is shown in Figure 3. Secondary seal leakage is drained to the sump. The pump shafts are long enough to prevent the oil wetted portion from contacting packing.

3.1.2 Standby Pump

A standby pump provides a reserve in the event of loop pump malfunction. This pump develops the same pressure as the loop pump, but has a smaller flow capacity. It is a constant-speed, triplex, positive-displacement type, with integral check valves. Austenitic stainless steel or equivalent corrosion-resistant material is used for all parts in contact with coolant. Shaft length is sufficient to prevent contamination of packing by oil.

The standby pump is energized by the Loop flow controller or manually from the plant control room.

FIGURE II-3
PUMP LEAKOFF SYSTEM
FLOW DIAGRAM

675C112

3.1.3 Interchanger

The interchanger recovers heat from the coolant leaving the supercritical fuel assembly by heating the inlet stream. This unit consists of three double-pipe coils connected in parallel, arranged concentrically about the vertical axis. The hot coolant stream flows through the inner pipe and the cold stream through the annulus. The interchanger is austenitic stainless steel with all joints welded. Spacers are provided between inner and outer pipes to assure concentricity.

3.1.4 Heater

The heater raises the coolant temperature to the required pressure tube inlet conditions and is controlled to maintain these conditions constant. The unit consists of forty-two individual heater sections, arranged in three parallel paths. The fourteen sections in each path are connected in series. Each heater section consists of a straight run of pipe containing a single immersion-type electric heater element. Coolant flows through the annulus formed by the heater element and the outer pipe. The pipe is austenitic stainless steel and the heater sheaths are Inconel. All piping joints are butt welded, or screwed and seal welded. Electrical connections for the individual heater elements are made through a high-pressure seal. Spacers are welded to the heater sheath to assure concentricity of heater tube and outer pipe.

Heater output is controlled by a saturable reactor which varies heater voltage and current. The saturable reactor is a variable impedance device with two windings, one for a-c power and one for d-c control on an iron core. The a-c winding is connected in series with the heaters. The impedance is varied by controlling the magnetic saturation in the iron core. A complete range of control of a-c power can be obtained in a smooth stepless manner by varying a small amount of d-c power.

3.1.5 Pressure Tube

The pressure tube holds the experimental fuel assembly in the reactor core and serves as a pressure boundary between reactor coolant and Supercritical Loop coolant. Supercritical Loop coolant enters near the top of the tube, flows downward along the tube wall, then turns and flows upward through the fuel assembly to the outlet connection. A series of thermal baffles between the tube wall and the inlet stream protect the tube wall against excessive thermal stresses. The tube is constructed of austenitic stainless steel.

3.1.6 High-Pressure Cooler

The high-pressure cooler reduces the temperature of the interchanger tube side stream to permit pressure reduction without flashing. The unit consists of a vertically-oriented double-pipe coil, with the process fluid in the inner tube and component cooling water in the annulus. The inner pipe is austenitic stainless steel and the outer pipe is carbon steel. All joints are welded. Spacers are welded to the inner tube to assure concentricity of the two pipes.

3.1.7 Low-Pressure Cooler

The low-pressure cooler further cools the process stream after it passes through the pressure-reducing valve. It also serves as a letdown device by reducing coolant pressure to the deaerator operating conditions. The unit is a vertically-oriented double-pipe coil, mounted concentrically with the high-pressure cooler. Process coolant flows in the inner pipe and component cooling water in the annulus. The inner pipe is austenitic stainless steel and the outer pipe is carbon steel. All joints are welded.

3.1.8 Deaerator

The deaerator separates and removes dissolved and entrained gases from the process fluid and provides coolant storage capacity and NPSH for the condensate pumps. The deaerator is a vertical cylindrical tank,

partially filled with Raschig ring packing. The packing which is used to produce increased liquid to gas surface area, is contained in a basket for ease of removal and replacement. Coolant enters through a spray nozzle at the top and flows downward through the packing. A liquid level is maintained in the bottom of the tank, and gases are removed from the space above this level and below the packing. The unit is of welded construction, except for a flanged top head closure and spray nozzle connection. All wetted surfaces, including Raschig rings, are austenitic stainless steel.

3.1.9 Condensate Pumps

Two condensate pumps circulate Loop coolant through the demineralizers to the loop pump suction. The pumps are centrifugal, canned-motor units, arranged to operate in series. The piping configuration also permits each pump to operate alone. All pump parts in contact with the coolant are fabricated of austenitic stainless steel or equivalent corrosion-resistant material.

The pumps are started and stopped manually by the operator.

3.1.10 Demineralizer

A flushable, mixed-bed demineralizer removes ionic impurities and corrosion products from the Loop coolant stream. An ammonium hydroxide form, nuclear grade resin is charged into the vessel. A retention screen beneath the resin bed prevents the loss of resin particles to the outlet line. The resin can be removed through a resin flush line above the retention screen. A screen at the inlet nozzle prevents resin from entering this line during backflush operations. The vessel is refilled with fresh resin through a fill line, which is also used for the insertion of resin sample probes. The demineralizer vessel and internals are austenitic stainless steel, with all joints and connections welded.

3.1.11 Filters

A cartridge-type filter removes resin fines which may have passed through the demineralizer retention screen from the loop coolant. The viscose filter cartridge may be removed from the filter container and replaced if it becomes fouled. The filter container is constructed of austenitic stainless steel. A second filter contains cartridges of a smaller pore size. This filter is provided to remove suspended corrosion in addition to resin fines. The filters are installed in parallel, with a control room operated switching system and a high Δp alarm installed.

3.1.12 Specimen Holders

Three specimen holders permit insertion of corrosion test specimens in the coolant flow stream. One holder is located downstream of the heater in the inlet leg and the other two on either side of the inter-changer in the outlet leg. Each holder consists of a coupon retainer assembly fitted snugly into a straight pipe section. Sample coupons slide into grooves in the retainer and are held in place by spring-loaded set screws. The retainer may be disassembled to allow observation of specimens without removing them. A high pressure coupling is used at one end of the holder for removal of the retainer from the pipe. All parts of the specimen holder are austenitic stainless steel.

3.1.13 Accumulator

An accumulator reduces pressure pulsations in the loop coolant flow stream. The unit is a cylindrical carbon steel vessel with an inside plastic coating for corrosion resistance. Physical separation between loop fluid and pressurizing gas is maintained by a rubber diaphragm.

3.1.14 Coolant Reservoir and Refill Tank

The coolant reservoir holds a supply of coolant under pressure for injection into the loop in case of loss-of-coolant or loss-of-flow accidents. The reservoir is a vertical, cylindrical carbon steel vessel. All joints and connections are welded, or screwed and seal-welded. Associated with the coolant reservoir is a small refill tank which can be operated remotely during reactor operation to maintain the water level in the reservoir. The refill system is shown in Figure 4.

FIGURE II-4
RESEVOIR REFILL SYSTEM FLOW DIAGRAM

3.1.15 Reservoir Gas Cylinder

The reservoir gas cylinder holds the pressurized inert gas used to drive the contents of the coolant reservoir into the Loop. The cylinder is carbon steel, with all joints welded.

3.1.16 Gas Compressor

The gas compressor charges the reservoir gas cylinder and maintains its pressure at a specified value. The unit consists of an air operator, a compression head and a plunger shaft connecting the two. An inert gas is supplied to the compression chamber from a commercial compressed gas cylinder. The plunger, moving in an oil-filled cylinder, imparts an oscillating motion to a flexible stainless steel diaphragm which compresses the gas in the head.

The compressor has stainless steel working parts, while the compression cylinder and oil reservoir are carbon steel. All valves and controls necessary for the operation of the compressor are supplied as an integral part of the unit.

3.1.17 Air Compressor

Two air compressors supply compressed air, as required, to the gas compressor, air dryer, and Loop instruments. Each unit is a conventional reciprocating design and includes a receiver tank. All valves and controls necessary for compressor operation are provided as part of the unit. The air system is shown in Figure 5.

3.1.18 Vacuum Pump

The vacuum pump removes a mixture of non-condensable gases and steam from the deaerator and maintains the required operating pressure. The pump is a single-stage, water-sealed centrifugal type. All pump parts in contact with the pumped fluid are bronze or cast iron. Closures and connections are either screwed, bolted, or flanged, with suitable gaskets.

FIGURE II-5
AIR SYSTEM FLOW DIAGRAM

8810000

3.1.19 Vacuum Pump Seal Water Reservoir

The vacuum pump seal water reservoir receives the mixture of water, steam and non-condensable gases discharged by the vacuum pump and provides a volume for separation of the gas and liquid phases. In addition, the unit acts as a standpipe to maintain an adequate supply of sealant for the vacuum pump. The reservoir consists of a vertical section of stainless steel pipe with all connections socket-welded.

A small electrically-heated steam generator, attached to the seal water reservoir, provides a diluent stream for the radiolytic and fission gases flowing to the recombiner. The unit is constructed of stainless steel, with socket-welded connections.

3.1.20 Vacuum Pump Seal Water Cooler

The vacuum pump seal water cooler removes the heat added to the water by the pump and maintains a constant sealant temperature entering the pump. The cooler is a double-pipe coil, with seal water in the inner tube and cooling water in the annulus. The inner tube is stainless steel and the outer tube copper.

3.1.21 Catalytic Recombiner

The catalytic recombiner removes hydrogen produced by radiolytic and thermal decomposition of ammonia plus radiolytic hydrogen and oxygen from the off-gas stream by recombining them into water vapor. Included in the recombiner package are a cylindrical carbon steel catalyst vessel, electric strip heaters, a carbon steel, finned-tube heat exchanger and an integral temperature controller. The heaters are attached to the catalyst vessel, under its thermal insulation.

The incoming mixture of hydrogen, nitrogen, oxygen, radioactive gases and steam flows through the catalyst bed where the hydrogen and oxygen are combined into water vapor. During operation with ammonia injection, air is bled into the mixture to supply sufficient oxygen to react with the excess hydrogen. The steam is condensed in the heat exchanger and the condensate is returned to the vacuum pump seal water reservoir. Non-condensable gases flow to waste disposal.

3.1.22 Oil Absorber

An oil absorber, located immediately after the air receiver removes oil from the instrument air. The unit consists of replaceable filter cartridges and a cylindrical carbon steel vessel.

3.1.23 Dryer

A dryer, located immediately down-stream from the oil absorber removes the water vapor from the instrument air. The unit consists of dual carbon steel vessels containing alumina desiccant. The vessels are regenerated alternately and automatically by air flow.

3.1.24 Air Filter

A cartridge type filter removes particulates from the instrument air supply to the gas compressor. The filter cartridge may be removed from the filter container and replaced upon fouling.

3.1.25 Head Tank

The head tank supplies makeup water to the Loop and provides net positive suction head for the loop pumps. The tank is a vertical, cylindrical, stainless steel vessel. An overflow line at the top of the tank is connected to the pressurizer discharge tank.

3.1.26 Feed Tank

The feed tank is used for mixing, storing and dispensing decontamination solutions. The tank is a vertical stainless steel vessel, open to atmosphere and provided with a bolted cover.

3.1.27 Emergency Condenser

The emergency condenser assists in core cooling in the event of a loss-of-coolant or extended loss-of-flow accident. In addition, this condenser removes residual heat from the fuel during decontamination, or when the Loop is drained for maintenance or is otherwise inoperative.

The unit consists of a pipe coil mounted in a vertical water-filled drum. Steam from the pressure tube outlet line enters the pipe coil at the top and is condensed as it flows downward through the coil. The condensate is drained to the pressure tube inlet line by gravity flow. An intermittent flow of makeup water balances losses due to vaporization of the water in the drum. The unit is austenitic stainless steel, using all-welded construction. An overflow and vacuum break are provided.

3.1.28 Ammonia Injection Pumps

Two variable flow metering pumps inject dilute ammonia solution into the loop. The pumps are diaphragm type units with fine micrometer type adjustment for varying solution injection rate. Normally one pump will be operating while the other will be at standby. The pumps are operated and adjusted manually. Adjustments will be based on loop ammonia concentration which will be determined by the use of the conductivity meter. All pump parts in contact with the solution are austenitic stainless steel.

Two storage tanks hold the solution supply to be injected by the pumps. The tanks are the atmospheric pressure, removable lid type and are constructed of austenitic stainless steel. The ammonia injection system is shown in Figure 6.

3.1.29 Reactor Bleed Cooler

The reactor bleed cooler removes heat from the reactor vessel head penetration nozzle bleed stream. The cooler consists of a coil of austenitic stainless steel tubing which is immersed in the storage well water. The required heat removal rate is provided by natural convection.

3.1.30 Sample Coolers

Three sample coolers reduce the sample stream temperatures sufficiently to permit letdown without flashing. Each cooler is a double-pipe coil unit. The inner tube, which contains the sample stream, is austenitic stainless steel, gold-plated on its internal surface. The gold plate allows removal of any sample residues without contamination by the tube material. Component cooling water flows in the annulus between the inner tube and the copper outer tube.

3.1.31 Sample Ion-Exchangers

Three sample ion-exchangers separate crud from the Loop coolant samples. Each unit consists of a section of austenitic stainless steel pipe, filled with mixed anion-cation exchange resin. Both upper and lower heads are removable to permit post-operational analysis of the material collected by the resin. Shutoff valves, disconnect couplings and external lead shielding are furnished as part of the unit.

3.1.32 Sample Vessel

A sample vessel is provided to collect samples for analysis of gases dissolved in the loop coolant. The unit is a cylindrical austenitic stainless steel vessel. Shut off valves and disconnect couplings are furnished as a part of the unit. It is located in the sample room, external to the reactor containment vessel.

3.1.33 Valves

Valves are located in the Supercritical Loop as shown on the Process Flow Diagrams. All process valves are austenitic stainless steel. Service valves for cooling water or air are brass or an equivalent material.

Manually operated stop valves permit changes in flow circuitry, venting, filling and draining of components and permit isolation of certain components for maintenance. Extension stems are provided for those valves not readily accessible to the operator. Check valves prevent reverse flow within the Loop and leakage from or into external plant systems.

Remotely operated stop valves are used to isolate Loop equipment not in use, to bypass various portions of the Loop, to isolate connections to other plant systems and to vent or drain components not accessible

during Loop operation or decontamination. All valves containing radioactive fluids have valve stem leakoffs or back seats to maintain essentially zero leakage to the atmosphere. Instrument valves and hermetically sealed solenoid valves are excepted from this requirement. The piping system for the valve leakoffs is shown in Figure 7.

Self-actuated, totally enclosed spring-loaded relief valves protect piping and components from overpressure. Relief valve locations and points of discharge are as follows:

On the outlet line from the pressure tube, discharging to the storage well, below normal water level;

On the discharge side of the loop pump and standby pump, discharging to the suction side of the pumps;

On the discharge side of the gas compressor, discharging to atmosphere;

On the makeup water line supplying the coolant reservoir, discharging to discharge tank;

On the Loop component cooling water supply line, discharging to atmosphere;

On the discharge side of the diluent steam generator, discharging to the discharge tank;

On the inlet side of each sample ion exchange column, discharging to the collection header.

3.1.34 Piping

All Supercritical Loop process piping is austenitic stainless steel. Service piping for component cooling water, gas or air is carbon steel

or copper. Piping joints in the process stream are welded except for special couplings at the pressure tube, specimen holders and gas sample holder to facilitate removal for inspection or maintenance, and screwed joints at the vacuum pump suction and discharge and screwed joints at several points in the low pressure parts of the loop. Every screwed joint is backed up by a gasketed fitting.

3.1.35 Thermal Insulation

Supercritical Loop piping, valves and equipment which operate at elevated temperatures are covered with thermal insulation where necessary to reduce heat losses. Insulation is provided on lines connecting the interchanger to the pressure tube and on the line from interchanger to high-pressure cooler. In addition, the inlet line to the emergency condenser, the heater and the interchanger are insulated. A portion of the loop piping and the pressure tube in the reactor compartment have metal jacket reflective insulation. All other insulation is canvas covered magnesia-type.

3.2 INSTRUMENTATION AND CONTROL

3.2.1 Temperatures

a. Pressure Tube Inlet Temperature, TR-X3

The temperature of the coolant entering the pressure tube is recorded on the Loop control board. This temperature is used as a check on the pressure tube inlet temperature control and for estimating pressure tube heat losses.

b. Pressure Tube Outlet Temperature, TRC-X4, TA-X19

A temperature recorder-controller measures the temperature at the pressure tube outlet and can supply a set-point signal to the Loop flow controller, FRC-X1 (Section 3.2.5a). The temperature is recorded on the Loop control board. An alarm in the control room

is actuated and the heater is shut off if the temperature approaches its maximum permissible value. (This control of flow rate will not be used for Task A of the development program.)

c. Heater Outlet Temperature, TRC-X9

A temperature recorder-controller on the heater outlet provides a set-point signal for the heater control, QC-X1 (Section 3.2.2a). The set-point signal is a function of the desired temperature and the difference between it and the actual temperature. The unit can also provide an alternate control signal for the interchanger bypass valve when experimental conditions call for the use of this valve. The heater outlet temperature is recorded on the Loop control board.

d. Heater Inlet Temperature, TRC-X10

A temperature detector is located on the heater inlet. The temperature is recorded on the Loop control board.

e. High-Pressure Cooler Outlet Temperature, TRC-X11, TA-X20

A temperature recorder-controller on the outlet of the high-pressure cooler controls component cooling water flow to the cooler to maintain a constant outlet temperature. An alarm on the Loop control board is actuated if the temperature exceeds its normal value by a specified amount. The temperature is also recorded on the Loop control board.

f. Low-Pressure Cooler Outlet Temperature, TRC-X18

A temperature recorder-controller on the outlet of the low-pressure cooler controls component cooling water flow to the cooler to maintain a constant outlet temperature. The temperature is recorded on the Loop control board.

g. Seal Water Cooler Outlet Temperature, TC-X21

A local temperature controller on the outlet of the seal water cooler controls component cooling water flow to the cooler to maintain a constant outlet temperature.

h. Fuel Assembly Temperatures, TR-X1 - 1 to 12, TA-X22

A multipoint temperature recorder on the Loop control board is used to monitor fuel assembly coolant inlet and outlet temperatures. The number and location of the temperature detectors varies, depending on the experiment in progress. Pressure tube design limits the maximum number to twelve. An alarm on the loop control board is actuated by a high inlet (TA-X22A) or a high outlet (TA-X22B) temperature. Fuel assembly inlet and outlet temperatures are recorded alternately.

i. Pressure Tube Adapter Temperature, TR-X1-12

A temperature detector is located on the pressure tube female flange adaptor. The temperature is recorded on a multipoint recorder located on the control board. An alarm (TA-X12) is actuated by a high adaptor temperature.

j. Interchanger Temperatures, TR-X1-13, TR-X1-14, TR-X1-15, TR-X2-4

Temperature detectors are located on the four lines entering and leaving the interchanger. These temperatures are recorded by the multipoint recorders on the Loop control board. The recorded temperatures permit evaluation of interchanger performance.

k. Reactor Head Nozzle Bleed Temperatures, TR-X1-16, TR-X2-12

Temperature detectors are located in the reactor head nozzle bleed line at the inlet (TR-X1-16) and outlet (TR-X2-12) of the reactor bleed cooler. These temperatures are recorded by the multipoint recorders on the Loop control board.

l. Sample Cooler Outlet Temperatures, TR-X2-1, TR-X2-2, TR-X2-3

A temperature detector is located on the process stream outlet of each sample cooler to monitor the sample ion-exchanger inlet temperature. The temperatures are recorded by the second multipoint recorder on the Loop control board.

m. Component Cooling Water Temperatures, TR-X2-5, TR-X2-7

Temperature detectors are located on the component cooling water supply (TR-X2-5) and return (TR-X2-7) lines. These temperatures are recorded by the second multipoint recorder on the Loop control board.

n. Condensate Pump Discharge Temperatures, TRC-X2-6, TA-X12

A temperature detector is located on the condensate pump discharge line. The temperature is recorded by the second multipoint recorder on the Loop control board. An alarm is actuated if the temperature exceeds the maximum allowable demineralizer inlet temperature.

o. Loop Safety Valve Discharge Temperature, TR-X2-8, TR-X2-9

Temperature detectors are located in the lines downstream of the Loop safety valves. These temperatures are recorded by the second multipoint recorder on the Loop control board. An increase in the temperature is an indication of safety valve operation or leakage.

p. Injection Line Temperature, TR-X2-10

A temperature detector is located on the injection line connected to the pressure tube outlet piping. This temperature is recorded by the second multipoint recorder on the Loop control board. This detector monitors emergency condenser inlet temperature.

q. Sample Temperature, TR-X2-11

A temperature detector is located on the sample header upstream of the deaerator. The temperature is recorded by the second multipoint recorder on the Loop control board.

r. Seal Water Temperature, TR-X2-13, TR-X2-14

Temperature detectors are located in the seal water reservoir (TR-X2-14) and in the outlet line (TR-X2-13) of the seal water cooler. These temperatures are recorded by the second multipoint recorder on the Loop control board to permit evaluation of the seal water cooler performance.

s. Recombiner Condenser Outlet Temperature, TR-X2-15

A temperature detector is located in the recombiner condenser condensate outlet line. This temperature is recorded by the second multipoint recorder on the Loop control board.

t. Heater Flow Blockage Temperature, TA-X23, TCX-23A, B, C

A temperature detector is located on the heated length of each parallel flow passage in the preheater. The sensor measures the outside wall temperature of the heater shell piping. If the piping temperature exceeds the design temperature, an alarm is given on the control board.

u. Recombiner Inlet and Outlet Temperatures, TR-X2-16A, B

Temperature detectors are located in the recombiner inlet and outlet lines. These temperatures are recorded by the second multipoint recorder on the Loop control board to permit evaluation of the recombiner performance.

v. Catalytic Recombiner Temperature, TIC-X24

A local temperature indicator-controller on the catalytic recombiner controls an electric heater in the recombiner to maintain the temperature of the catalyst bed above the saturation temperature of steam in the system.

w. Diluent Steam Temperature, TC-X25

A local temperature controller on the inlet line of the catalytic recombiner controls an electric heater on the line to raise the temperature of the diluent steam above its saturation point.

3.2.2 Heat Content and Power

a. Heater Control QC-X1

The heater control regulates pressure tube inlet temperature by

varying heater power output. This unit normally receives one input signal and a set-point signal. The set-point signal is provided by the heater outlet temperature recorder-controller, TRC-X9 (Section 3.2.1c) during supercritical operation.

TRC-X9 measures the actual heater outlet temperature and this result is compared with the preset value. If a differential exists, a control signal is transmitted to a power controller which supplies a direct-current control voltage to the saturable reactor. The saturable reactor adjusts heater electrical supply to the required level. An additional control exists in that the heater may be manually controlled to give a set power output.

In the event of a loss-of-flow or loss-of-coolant accident, a signal from the instrument detecting the accident (See Sections 3.2.3b, 3.2.3c, 3.2.5a) to the heater control shuts off the heater. Heater shutoff signals are also generated by instruments detecting excessive pressure tube differential pressure (Section 3.2.3m), high pressure tube outlet temperature (Section 3.2.1b) and low bleed water flow.

b. Heater Power, QRC-X3

A thermal converter on the saturable reactor input generates a signal proportional to voltage which is recorded on the Loop control board.

3.2.3 Pressures

a. Accumulator Pressure, PR-X2

The pressure in the accumulator gas space is recorded on the Loop control board.

b. Pressure Tube Differential Pressure, ΔPRC-X4, ΔPA-X5

A differential pressure recorder-controller across the pressure tube controls coolant injection and provides a reactor scram signal in the event of a loss-of-coolant accident. Under normal operating conditions, pressure drop across the tube is positive (i.e., inlet pressure exceeds outlet pressure). However, a pipe break between

the loop pump and the pressure tube inlet will result in a rapid flow reversal and a concurrent pressure drop reversal. Upon detecting this change, reverse safety injection is initiated when the controller opens the coolant injection valve to the pressure tube outlet (Section 3.2.5b), closes the Loop pressure control valve (Section 3.2.3c), sends a heater shutoff signal to the heater control, QC-X1, (Section 3.2.2a) and actuates an alarm on the Loop control board. The differential pressure signal is also recorded on the Loop control board.

c. Loop Pressure Control, PRC-X6, PA-X3, PA-X7

A pressure recorder-controller on the pressure tube inlet regulates a control valve to maintain a constant inlet pressure, and provides a reactor scram signal in the event of a loss-of-coolant accident. An alarm on the Loop control board is actuated to warn of high pressure or low pressure conditions, and a second alarm is activated by the loss-of-coolant scram signal. In addition, an output signal is sent to the heater control, QC-X1 (Section 3.2.2a) to shut off the heater upon loss of coolant. The pressure is recorded on the Loop control board.

The normal pressure control function of this instrument is suppressed during loss-of-coolant emergency by an override signal. When coolant is to be injected into the pressure tube outlet, the differential-pressure controller, Δ PRC-X4, (Section 3.2.3b), closes the pressure control valve so that injection flow passes through the pressure tube. The pressure controller is reset manually.

d. Compressor Discharge Pressure, PC-X10, PA-X13

A local pressure controller on the gas header supplying the reservoir gas cylinder operates the compressor to maintain cylinder pressure above a preset value. The instrument provides an on-off signal to the compressor motor and a low-pressure signal to an alarm on the Loop control board.

e. Gas Header Pressure, PI-X11

A local pressure detector on the gas header monitors gas pressure during coolant reservoir filling operations and provides a check on the compressor control PC-X10, (Section 3.2.3d), during tests.

f. Pressure Tube Outlet Pressure, PC-X14, PA-X12

A pressure switch at the outlet of the pressure tube actuates an alarm on the Loop control board when the pressure falls below a set value. The alarm provides an independent verification of the occurrence of a loss-of-coolant accident.

g. Loop Pump Discharge Pressure, PR-X20

A pressure detector on the loop pump discharge piping sends a signal to a recorder on the Loop control board. This reading and the accumulator pressure reading, PR-X2 (Section 3.2.3a) are recorded on the same chart.

h. Deaerator Pressure, PRC-X22, PA-X8

A pressure recorder-controller on the deaerator prevents excessive pressure on the vacuum pump by closing the pump inlet valve if deaerator pressure exceeds a preset value. An alarm on the Loop control board is actuated by a high-pressure signal. The deaerator pressure is continuously recorded on the Loop control board.

i. Interchanger Differential Pressure, Δ PI-X23, Δ PA-X26

A differential-pressure detector on the interchanger provides a continuous reading of the difference between cold-side inlet pressure and hot-side outlet pressure on the Loop control board. This pressure difference reading is used in predicting and evaluating interchanger performance. An alarm on the Loop control board is actuated when the differential pressure approaches the external design pressure of the interchanger inner tube.

j. Condensate Pump Discharge Pressure, PI-X24

A pressure indicator on the condensate pump discharge line provides a continuous reading of pump discharge pressure on the Loop control board.

k. High-Pressure Cooler Outlet Pressure, PI-X25

A local pressure indicator is located on the outlet of the high-pressure cooler. This instrument is used during Loop shakedown runs as a check on the accuracy and response of the Loop pressure control, PRC-X6 (Section 3.2.3c).

l. Pressure Tube Differential Pressure, Δ PC-X26, Δ PC-X28, Δ PA-X29

Two differential pressure switches across the pressure tube protect the interchanger tube against excessive differential pressure if flow through the pressure tube is blocked. The first switch (Δ PC-X26) is set below the tube external design pressure and the second (Δ PC-X28) is set at that pressure. When the set-point of the first switch is reached, the heater is shut off. If the differential pressure increases to the set-point of the second switch, the pressure tube bypass valve is opened, an alarm on the Loop control board is actuated and the heater shutoff signal is repeated.

m. Filter Differential Pressure, Δ PC-X30, Δ PA-X31

A differential pressure switch across the filter monitors the performance of the unit. The switch operates a signal light on the Loop control board when pressure drop reaches a value which characterizes a fouled filter element.

n. Sample Pressure, PI-X32

A local pressure indicator is located in the sample room external to the reactor containment. It monitors the pressure of the sample fluid being withdrawn from the loop.

o. Instrument Air Pressure, PA-X50

A pressure alarm is located on the instrument airline between the compressors and the purification components to determine excess instrumentation pressure. An alarm on the Loop control board is actuated by the signal.

p. Catalytic Recombiner Air Feed Pressure, PIX-60

A local instrument is used to indicate the pressure of the air feed to the catalytic recombiner.

3.2.4 Level

a. Head Tank Level, LIC-X1

A level indicator-controller operates a makeup valve to maintain the water inventory in the head tank above a preset level. The instrument provides a continuous level indication on the Loop control board.

b. Emergency Consenser Level, LC-X2

An on-off level controller on the emergency condenser operates a makeup valve to replace vaporization losses and keep the condenser coil submerged at all times.

c. Deaerator Level, LIC-X3

A level indicator-controller regulates a control valve to maintain a constant liquid level in the deaerator. The valve throttles the condensate pump discharge flow to match the inflow to the deaerator. A continuous level indication is provided on the Loop control board.

d. Loop Vent Line Level, LI-X4

A local level indicator in the Loop vent line is used while filling the Loop. The appearance of a water level at this instrument is an indication that the Loop is full.

e. Coolant Reservoir Level, LIC-X6, LA-X7

A level-indicator controller positions a three-way valve to admit makeup water to the Loop when the coolant reservoir is nearly empty. The valve simultaneously closes off the reservoir to prevent injection of the pressurizing gas into the Loop. An alarm on the Loop control board is actuated by a low-level signal. The reservoir level is continuously indicated on the Loop control board to provide additional notice of leakage from the vessel.

f. Deaerator Level, LC-X8, LA-X9

A probe-type level controller, mounted in the lower plenum of the deaerator, prevents water overflow to the vacuum pump by closing the pump inlet valve if liquid level exceeds a fixed value. The instrument simultaneously actuates an alarm on the Loop control board.

g. Vacuum Pump Seal Water Reservoir Level, LIC-X10

A level indicator-controller operates a drain valve to permit the liquid level in the seal water reservoir from rising above a specified point. A continuous level indication is provided on the Loop control board.

h. Pump Leakoff Drain Tank Level, LC-X13

A high-low probe type level controller, mounted on the pump leakoff drain tank, operates a drain tank pump. The pump empties the drain tank of pump leakage that has collected in it and transfers it back to the deaerator by way of the collection header.

i. Ammonia Injection Solution Tank Level LI-X80, LI-X81

Local level indicators are used on the ammonia injection solution tanks to monitor the solution level. The sight type indicators are located in the auxiliary equipment room exterior to the vapor container.

3.2.5 Flows

a. Loop Flow Control, FRC-X1, FA-X2, FA-X7

A flow recorder-controller on the loop pump discharge line maintains the required flow during normal Loop operation and initiates protective measures in the event of a loss-of-flow accident.

During normal operation of the Supercritical Loop, the instrument receives and transmits the following signals:

1. A manual input signal which sets the nominal flow rate for the particular experiment.
2. An input signal from the Loop flow detector. This signal is compared with the set-point value in the controller.
3. An output signal to the loop pump bypass valve (FRC-X1 V6) operator, which adjusts the valve position to maintain the correct flow.
4. An output signal to a flow recorder mounted on the Loop control board.

In the event of a loss of flow accident, FRC-X1 is utilized in the following manners.

Control A, partial loss-of-flow accident, (defined by: 80% >flow> 50% of set-point). The instrument receives and transmits the following signals:

1. A manual input signal which sets the nominal flow rate for the particular experiment.

2. An input signal from the Loop flow detector. This signal is compared with the limit set-points to define the accident.
3. An output signal to the heater control, QC-X1 (Section 3.2.2a) to shut off the heater.
4. An output signal to the standby pump motor starter to start the pump if it is not already operating.
5. An output signal to activate a partial-loss-of-flow alarm (FA-X2) on the Loop control board.
6. An output signal to a flow recorder mounted on the Loop control board.

Control B, a total loss-of-flow accident, (defined as reduction in flow below 50% of set-point). The instrument receives and transmits the same signals as during a partial loss-of-flow, with the following additions:

1. An output signal to scram the reactor and activate an alarm on the reactor scram panel (FA-X7). To prevent spurious scrams, a time delay is incorporated in this circuit. If the flow is brought above the 50% limit before the delay time is over, the scram signal is blocked. The time delay is nominally set at 4 seconds.
2. An output signal to the coolant reservoir isolation valve operator to open the valve with the same time delay.

Control C, a total loss-of-flow accident, as Control B, with the same output signals. Control C is set for 30% of set-point flow with no time delay.

b. Reverse Safety Injection Flow, FIC-X3 - Loss of Coolant

An indicator-controller on the safety injection line regulates a control valve to maintain a constant injection rate. The controller is normally inoperative and must be activated by a loss-of-coolant signal from the pressure tube differential pressure controller, ΔPRC-X4 (Section 3.2.3b). Once activated, the injection flow controller continues in operation until manually shut off. The injection flow rate into the pressure tube is indicated on the Loop control board.

c. Makeup Water Flow, FR-X8

The makeup water flow to the head tank is recorded on the Loop control board. This record is used in evaluating the water consumption of the Loop and also as an indication of leakage through the head tank or emergency condenser makeup valves.

d. Reactor Head Nozzle Bleed Flow, FIC-X9

A flow indicator-controller on the reactor head nozzle bleed line regulates a control valve to maintain a constant bleed flow. A continuous flow indication is provided on the Loop control board.

e. Pump Packing Gland Flow, FI-X10, FA-X10

A flow detector on the pump gland leakoff manifold provides a continuous indication on the Loop control board of the leakage through the packing gland of the operating pumps. This reading assists in monitoring pump packing performance. Three-way bypass valves allow the performance of individual pumps to be monitored. An alarm on the Loop control panel indicates when the leakage rate has exceeded the preset allowable rate.

f. Sample Flow, FR-X15, FR-X16, FR-X17

Flow recorders in each sample path measure the sample flow. Each flow is recorded on the Loop control board. The records are used in making quantitative studies of crud level in the sample streams.

g. Sample Flow, FI-X18

A local instrument in the sample room indicates sample flow rate.

h. Catalytic Recombiner Air Feed Flow, FI-X20

A local instrument is used to indicate the flow rate of the air feed to the catalytic recombinder.

3.2.6 Radiation

a. Condensate Pump Outlet Stream Radiation Level, RIC-X1, RA-X2

A radiation detector-controller in the line downstream of the condensate pumps sends a signal to an indicator on the Loop control board. This instrument also actuates an alarm on the Loop control board upon detecting a high radiation level. The indication is a measure of the deaerator efficiency and of the demineralizer inlet conditions.

3.2.7 Valve Operator Interlocks

a. Pressure Tube Isolation and Loop Bypass Valves, HC-X24, HC-X25, HC-X26

The pressure tube isolation and Loop bypass valve controls are interlocked to prevent accidental isolation of the main process line. The interlock does not permit the isolation valves, HC-X24 and HC-X26 to be closed until the bypass valve, HC-X25, is open.

3.2.8 Conductivity

a. Loop Coolant Ammonia Concentration Conductivity Indicator, CI-X1

A conductivity probe in the S-3 sample line upstream of the pressure tube sends a signal to an indicator on the Loop control board. The indication is a measure of ammonia concentration in the Loop coolant feed to the pressure tube which is used to determine ammonia injection rates.

4.0 DESIGN BASES

4.1 GENERAL

The Saxton Supercritical Loop is designed to provide a coolant steam of specified temperature, pressure and flow rate to the experimental fuel assembly. Figure 8 indicates the operating range of the loop for supercritical pressure and two power levels. The loop is sized to remove 392,000 Btu/hr (115 KW) from the nuclear fuel, in addition to the heat load imposed by coolant stream preheating.

4.2 COMPONENTS

Loop Pump

The loop pump is designed to deliver a flow rate sufficient to provide a mass velocity of 2×10^6 lb/hr ft² through the fuel elements. The pump is sized to provide a discharge pressure equal to the sum of the maximum required pressure tube outlet pressure of 4,000 psig and the pressure loss, at rated flow, in the pipe and equipment between pump discharge and pressure tube outlet. Pump design pressure is set approximately 10% above maximum discharge pressure.

Standby Pump

The standby pump is designed to deliver a flow rate sufficient to cool the fuel assembly under full power conditions, with the heater shut off. Discharge and design pressures are equal to the corresponding values for the loop pump.

Interchanger

The interchanger is designed to recover the maximum possible amount of heat within the limits imposed by space requirements and thermodynamics. The thermodynamic limitation is the result of the rapid change in physical properties of water near the critical point, which causes a reduction in temperature difference between the streams. The increase in surface area required to remove more heat is proportionately far greater than the benefits gained by such additional heat removal.

Figure II-8

Saxton Supercritical Loop

Range of Operation

The design pressure of the inlet stream (shell) side of the unit is the same as that of the "ultimate" pressure tube, which is the limiting high-pressure component. The inner tube wall thickness is sized for the greatest pressure differential across the tube wall at maximum flow conditions, plus a suitable safety margin. By passing the cooler stream through the shell side, heat losses to ambient air are minimized. Three parallel paths are used to reduce the pressure drop through the interchanger.

Heater

The heater is designed to satisfy all pressure tube inlet enthalpy requirements set by the proposed experimental program. (Maximum inlet enthalpy is approximately 1400 Btu/lb for supercritical operation.) Three parallel flow paths are used to reduce pressure losses in the unit. To take advantage of the higher surface heat fluxes permissible with lower fluid temperatures, each path is divided into three groups of heater elements. The elements in each group are designed for a fixed heat flux and a maximum sheath temperature specified by the heater manufacturer.

The design pressure of the heater elements is the same as that of the "ultimate" pressure tube. All heater elements are identical in design to simplify maintenance.

Pressure Tube

The pressure tube is sized to fit through the appropriate adapter in the Saxton reactor vessel head and into a special modified fuel element in the reactor core. The tube internals are designed to support the fuel assembly and experimental instrumentation. Design of the thermal baffles is based on limiting pressure tube wall temperature to 675°F and reducing heat losses to the reactor coolant as much as possible. The pressure tube design pressure is based on the operating pressures required by the experimental program. Since Loop operating pressure

may be increased as experiments progress, several pressure tubes may be required. The first unit will be designed for a pressure lower than the maximum anticipated operating pressure. A different, "ultimate" tube would be designed for the maximum expected pressure plus the safety margin specified by applicable codes. All pressure tubes are also designed for an external pressure equal to reactor vessel design pressure.

Since the number of loop startup and shutdown cycles is not large, fatigue considerations are of minor significance in the pressure tube design. The tube is capable of withstanding the thermal stresses resulting from 1000 startup and shutdown cycles at heatup or cooldown rates in excess of 600°F/min.

High-Pressure Cooler

The high-pressure cooler is designed to reduce the process stream temperature to a point where no flashing occurs in the pressure control valve. The design pressure of the process fluid (tube) side of the unit is the same as that of the "ultimate" pressure tube. The cooling water (shell) side is designed for the same pressure as the component cooling system.

Low-Pressure Cooler

The low-pressure cooler is designed to reduce the process stream temperature below the maximum allowable demineralizer operating temperature. In addition, the process fluid (tube) side is sized to provide the pressure drop required between pressure control valve outlet and deaerator inlet. Design pressure of the cooling water (shell) side is the same as that of the component cooling system.

Deaerator

The deaerator is designed to separate gases contained in the process stream from the carrier liquid and provide an essentially gas-free outlet stream. The unit is designed for pressures ranging from full vacuum to a positive pressure in excess of the maximum expected value.

Condensate Pumps

Each condensate pump is sized to deliver the Loop design flow to the loop pump suction at a pressure equal to the static pressure provided by the head tank. The two pumps, operating in series, are designed to meet the combined maximum flow and NPSH requirements of the loop pump and standby pump. In addition, the shutoff head of the two condensate pumps is chosen to permit the circulation of a small flow through the entire Loop with the loop pump and standby pump shut down. The pump design pressure is based on shutoff head developed, plus a suitable margin. Each pump is also designed to withstand a full internal vacuum when shut down.

Demineralizer

The demineralizer is designed to operate continuously for approximately 5 months with an influent soluble impurity concentration of 100 parts per billion (ppb). The unit is sized to purify a flow equal to the maximum loop pump flow. In the event of a major core failure, the demineralizer is capable of purifying the coolant stream sufficiently to permit maintenance, although a change of resin may be required.

The design pressure of the demineralizer is set above the shutoff head of the two condensate pumps in series.

Filters

The filters are designed to pass the flow rate of both condensate pumps and to collect particulate matter 25 microns and larger. This size is selected to include material which might damage the loop pump or foul

heat transfer surfaces. The filter cartridges are sized to permit a minimum of six weeks operation before replacement is required. Design pressure for the units is equal to that of the demineralizer.

Specimen Holder

Each specimen holder is designed to hold twenty individual sample coupons. The holders are sized to fit inside a section of 1-1/2-inch double-extra-strong pipe. In addition, specimen holders 1 and 3 are designed to produce a flow velocity of 180 to 200 feet per second along the specimen coupons.

Accumulator

The accumulator is sized to limit Loop pressure fluctuations to 50 psi with both pumps operating and an initial precharge pressure of 2000 psia. With only one pump operating, or with a higher precharge pressure, the pressure fluctuations will be smaller. The unit is designed for the maximum loop pump discharge pressure, plus a suitable margin.

Coolant Reservoir

The coolant reservoir is sized to hold a volume of water sufficient for 2-1/2 minutes of flow at a fixed rate of 10 GPM. The required volume was chosen by balancing reservoir size and cost against time needed to place other protective equipment in operation and the cost of the other equipment. Design pressure for the reservoir is equal to that of the accumulator.

Reservoir Gas Cylinder

The reservoir gas cylinder is sized to provide an injection pressure in excess of the maximum Loop operating pressure. In addition, the gas capacity is large enough to maintain an injection pressure of at least 500 psia when the coolant reservoir is empty. Design pressure for the cylinder is equal to that of the accumulator.

Gas Compressor

The gas compressor is sized to fill the reservoir gas cylinder to its operating pressure in 10 hours. This capacity is also sufficient to make up any expected gas leakage.

Air Compressor

The two air compressors are sized to deliver air at the flow and pressure required by the gas compressor and all air-operated instrumentation. The receiver tanks are sized to hold a supply of air sufficient for several minutes operation.

Vacuum Pump

The vacuum pump is designed to remove gases from the process stream at the deaerator in a quantity sufficient to maintain oxygen concentration in the deaerator effluent below 0.1 parts per million (ppm). The pump capacity is sufficient to handle up to 2 lbs/hr of water vapor along with the gases. The pump is designed to discharge against a pressure equal to the sum of RWDF operating pressure and pressure losses in the piping and equipment between the pump and RWDF.

Vacuum Pump Seal Water Reservoir

The seal water reservoir is designed to provide sufficient separation volume for the liquid-gas mixture delivered by the vacuum pump. The attached steam generator is designed to provide the diluent steam flow specified for the recombiner. Both units are designed for the vacuum pump discharge pressure plus a suitable margin.

Catalytic Recombiner and Recombiner Condenser

The radiolytic gas production in the supercritical loop is based on an ammonium decomposition rate for the anticipated loop concentration at loop environmental conditions.

The catalytic recombiner is designed to convert the entire quantity of hydrogen, mixed with suitable quantities of oxygen through an air bleed, to water. Diluent requirements for the unit are satisfied by the water vapor mixed with the inlet gas stream.

The unit is designed for full vacuum conditions or an internal pressure equal to the deaerator design pressure. The electric strip heaters are designed to maintain a catalyst bed temperature above the saturation temperature of the incoming gas-steam mixture. Heating the bed avoids condensation, which is detrimental to operation of the recombiner. The recombiner condenser is sized to condense all vapor in the stream leaving the recombiner and reduce condensate temperature to a maximum of 130°F.

Head Tank

The head tank is sized to accommodate the expansion of loop coolant during heatup and to contain the overflow from the loop after operation of the coolant reservoir. Design pressure for the tank is equal to that for the pressurizer discharge tank.

Feed Tank

The feed tank is sized to hold a volume of liquid somewhat larger than the loop volume at normal operating conditions. This permits filling the loop with contamination solution in a single batch.

Emergency Condenser

The emergency condenser is designed to remove the residual heat generated by the fuel assembly, beginning two minutes after scram. Heat transfer calculations are based on boiling of the cooling water in the shell.

The tube side of the condenser is designed for the same pressure as the "ultimate" pressure tube. Arrangement of the tube coil is designed to promote natural circulation of the steam and condensate.

Sample Coolers

Each sample cooler is designed to cool the sample stream to the saturation temperature corresponding to deaerator operating pressure. The sample stream (tube) side of each unit is designed for the same pressure as the heater. Each cooling water (shell) side has the same design pressure as the component cooling system.

Sample Ion-Exchangers

Each sample ion-exchanger is designed to remove 100 ppb of soluble impurities and 500 ppb of particulate impurities from the sample stream for a period of 1000 hours (six weeks). The columns are designed to permit removal of the resin bed as a unit for chemical analysis. Design pressures for the units are full vacuum and a positive pressure in excess of the deaerator design pressure.

Pressure Relief Valves and Rupture Discs

The loop safety valves (PSV-1, PSV-2) on the outlet side of the pressure tube are each sized to relieve one-half of the maximum combined flow of the loop pump and standby pump. This capacity is considerably in excess of that required to relieve the expansion of loop coolant due to maximum fuel element input with no heat removal. The valves are set at the design pressure of the pressure tube installed in the loop.

The pressure relief valve (PSV-3) on the loop pump discharge is sized for the maximum combined flow of the loop pump and standby pump. To prevent this valve from lifting before the loop safety valves operate, its set pressure is 5% higher than the maximum expected pump discharge pressure.

The relief valve (PSV-4) on the discharge side of the gas compressor protects the high-pressure gas equipment from overpressure. The valve is sized to relieve a gas flow of 20 times the small nominal compressor discharge rate, since suction pressure conditions and compressor size as purchased could result in higher flows. Set pressure for the valve equals design pressure for the gas equipment.

The relief valve (PSV-5) on the makeup water line to the coolant reservoir protects the plant service water system from overpressure due to leakage of high-pressure water from the reservoir. Valve capacity is estimated on the basis of 0.1 gal/sec leakage. Valve set pressure corresponds to the service water system design pressure.

The relief valve (PSV-6) on the cooling water supply line protects the cooling water piping from overpressure due to accidental isolation of this section of piping. The valve is sized to relieve the volumetric expansion of the isolated cooling water with the loop operating at maximum power. Valve set pressure is equal to component cooling system design pressure.

A rupture disc (RD-1) is located on the deaerator to protect the unit from overpressure. The disc is sized to pass the flow from the low-pressure cooler rupture disc (see below).

A rupture disc (RD-2) is located on the low-pressure cooler inlet line to protect the unit from overpressure if the high pressure cooler fails. The disc is sized to pass the steam portion of the combined loop pump and standby pump flow at maximum interchanger exit enthalpy. Bursting pressure is equal to low-pressure cooler design pressure.

Piping

One-inch pipe is designated as the "standard" size for Supercritical Loop process piping, even though flow velocities at some points are considerably lower than generally used in nuclear plants. Larger pipe sizes are specified in sections where pressure drop is critical, such as the connecting piping between pressure tube outlet and interchanger inlet.

Valves

All valves in the Supercritical Loop process stream, except pressure-reducing valves, are of the full-ported design to minimize pressure drop. All air-operated control valves carrying Loop coolant are provided with a stuffing box and leakoff connection, with the exception of the demineralizer resin flush and drain valves. These are low-pressure ball valves which are used infrequently. All manual high-pressure valves are provided with backseats to prevent stem leakage.

4.3 CODE REQUIREMENTS

The design of all components and piping in the Saxton Supercritical Loop complies with existing codes and regulations, including special interpretations applicable to nuclear plants. Table I lists code requirements for each component. Component design conditions are tabulated in Section 6.

4.4 THERMAL INSULATION

All thermal insulation is designed to reduce heat losses to a minimum consistent with space requirements and cost. Insulation on piping located in the storage well is designed to be submerged in boric acid solutions for extended periods without loss of insulating properties.

TABLE II-1
CODE CRITERIA

<u>Component</u>	<u>Codes</u>
Loop Pumps	No Code
Standby Pump	No Code
Interchanger	*ASME VIII, Nuclear Case 1273N
Heater (shell only)	**ASME I, Nuclear Case 1273N
Pressure Tube	ASME VIII, Nuclear Case 1273N
High-Pressure Cooler	ASME VIII, Nuclear Case 1273N
Low-Pressure Cooler	ASME VIII, Nuclear Case 1270N (Secondary Vessel)
Deaerator	ASME VIII, Nuclear Case 1270N (Secondary Vessel)
Condensate Pumps	No Code
Demineralizer	ASME VIII, Nuclear Case 1270N (Secondary Vessel)
Filter	No Code
Specimen Holders	No Code
Accumulator	ASME VIII (No Code Stamp)
Coolant Reservoir	ASME VIII
Reservoir Gas Cylinder	ASME VIII
Gas Compressor	No Code
Vacuum Pump	No Code
Catalytic Recombiner	ASME VIII, Nuclear Case 1270N (Secondary Vessel)
Dryer	No Code
Head Tank	ASME VIII (No Code Stamp)
Feed Tank	No Code (Open Tank)
Emergency Condenser	ASME VIII, Nuclear Case 1273N
Sample Ion-Exchangers	No Code
Reactor Bleed Cooler	No Code
Piping	ASME I

*ASME VIII - American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section VIII, 1962 Edition.

**ASME I - American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section I, 1962 Edition.

4.5 ELECTRICAL POWER SUPPLY

The main 440 V power supply to the Supercritical Loop is independent of the Saxton Reactor Plant Electrical Service System. The Supercritical Loop 440 V bus will supply power to all supercritical equipment and controls, except for the standby pump and one condensate pump, which will be supplied from a motor control center of the plant electrical system.

A group of critical instruments and controls, listed below draws power from the plant instrumentation bus. The battery-powered plant inverter provides emergency power for this bus to insure that these controls will be available if other power supplies are lost.

<u>Instrument</u>	<u>Title</u>
TRC-X4	Pressure Tube Outlet Temperature Control
ΔPRC-X4	Pressure Tube Differential Pressure
PRC-X6	Loop Pressure Control
LIC-X6	Coolant Reservoir Level
FRC-X1	Loop Flow Control

4.6 INSTRUMENTATION AND CONTROL RESPONSE CHARACTERISTICS

The instrumentation and control response time is defined as follows:

a. On-Off Control Systems

The response time is defined as the total elapsed time for the final element action to be completed after a step input at the detector from 5 percent of the controller span below to 5 percent of the controller span above the control set-point.

b. Proportional Control Systems

The response time is defined as the total elapsed time required for the final control element to move to 63.2 percent of the proper position, after a step change of 10 percent of the controller span in the process variable.

GENERAL PURPOSE

INSTRUMENTATION AND CONTROL RESPONSE TIMES

<u>Process Variable</u>	<u>Required Response Time, Seconds</u>
Temperature	<10
Flow	< 2
Pressure	< 2
Water Level	< 2
Radiation	< 2

The control functions requiring more rapid response characteristics are:

<u>Control Function</u>	<u>Required Response time, Seconds</u>
Coolant Injection Actuation (for loss-of-flow and loss-of-coolant)	< 1
Heater Control	< 5
Heater Shutoff (loss-of-flow)	< 1

4.7 WATER CHEMISTRY

The Supercritical Loop is filled with demineralized water from the Saxton plant supply. Ammonia is added to the water in the loop to suppress radiolytic decomposition of the water. The specifications for the Saxton plant demineralized water supply are as follows:

a. Conductivity	< 0.2 micromho/cm
b. pH (at 25°C)	6.5 - 7.5
c. Oxygen	< 0.007 ppm
d. Chloride	< 0.05 ppm
e. Total solids	< 0.1 ppm

The desired ammonia concentration for the loop coolant is 7 - 8 ppm

5.0 OPERATION

5.1 LOOP STARTUP

Loop startup is defined as the sequence of operations which brings the Supercritical Loop from cold shutdown to a specified operating condition.

Prior to initiation of plant heatup, the main process piping and equipment, coolant reservoir, safety injection lines and head tank are filled with demineralized water. The system is initially vented to the vapor container. Removal of entrained gas is completed by operating the vacuum pump and the condensate pumps until the deaerator pressure reaches a constant value. At the same time, the gas compressor is operated to fill the reservoir gas cylinder and precharge the accumulator. When these operations are completed, the loop pressure control is set for the desired pressure and the loop pump started. As soon as component cooling flow to the coolers is established, the loop is ready for heatup. Heatup of the reactor primary system and the supercritical loop is done concurrently.

Heatup of the loop is initiated by setting the heater control to produce an outlet temperature of 200°F, which turns on the heater automatically. Using the heater control and loop flow control, the temperature of the process stream at the heater outlet is raised to approximately 600°F in 100°F steps, allowing approximately 5 minutes for each step. At this time the controls are set to maintain steady-state conditions in the loop. Since the loop heatup rate is much greater than that of the main coolant system, heat is transferred from the pressure tube to the coolant in the reactor vessel.

The Supercritical Loop is held at steady-state conditions until the reactor has been brought to its desired operating condition. As power generation in the supercritical fuel assembly begins, adjustments are made to the control settings to compensate for the additional heat input. Once reactor conditions have been stabilized, Supercritical Loop heatup is started, using the same stepwise procedure and heatup rate as before. As conditions approach their specified values, final trim adjustments are made and the loop placed under full automatic control.

5.2 NORMAL OPERATION

Normal operation includes steady-state experimental operation at either supercritical or subcritical pressures and hot standby operation. Steady-state operation includes all transients imposed on the loop by normal reactor plant load changes.

5.2.1 Supercritical Pressure Operation

Since the Supercritical Loop power level is directly dependent on reactor power and cannot be separately controlled, the loop control system compensates for power transients by varying heater power. During steady-state supercritical operation, coolant pressure is held constant at or near a specified value by the loop pressure control valve. When test conditions are to be changed, a stepwise procedure is used to assure that no operating limitations will be exceeded.

Gas removal equipment operates continuously during supercritical operation to maintain constant deaerator pressure. When corrosion specimens are undergoing test, the specimen holder sample trains are also in continuous operation. Demineralizer samples are taken on a regular schedule, which may be modified by results of the sample analysis.

The range of conditions over which the loop is permitted to operate is illustrated in Figure 8, which represents the allowable range for a full-power fuel assembly and an assembly generating two-thirds of full power. The lower boundaries of the two areas are defined by the maximum permissible fuel cladding surface temperature, while the upper boundary for the 80 KW fuel assembly is fixed by maximum heater capacity. Open boundaries (no solid line) represent arbitrary operating limits specified by the experimental program rather than by equipment limitations.

5.2.2 Supercritical Pressure Operation*

The significant difference between operation at subcritical pressures and operation at supercritical pressures is the method of controlling the heater. Instead of using heater outlet temperature as the fundamental control variable, a calorimeter control system must be designed and placed in operation to provide a signal proportional to fluid enthalpy at the heater outlet. This signal will provide a set-point for controlling the heater. All other equipment functions in essentially the same manner for both subcritical and supercritical operation.

5.2.3 Hot Standby

If the reactor plant is at power, heat is generated in the Supercritical Loop fuel assembly. Thus, even though experimental operation of the Supercritical Loop is temporarily halted, the fuel assembly must still be cooled. The loop condition required for this operation is defined as a hot standby condition.

To achieve a hot standby condition, the heater is shut off and adjustments are made in pressure and flow control set-points to bring loop temperature and pressure to approximately 2000 psia and 530°F. These

* Operation at subcritical pressures is not included in the initial series of tests.

conditions correspond to reactor nominal operating conditions and thus effectively eliminate any pressure differential or heat transfer across the pressure tube wall. During hot standby, sampling lines are shut off, although periodic sampling of the demineralizer influent and effluent may continue. Gas removal equipment remains in operation, since radiolytic gas generation continues as long as neutron and gamma energy is absorbed by the coolant in the pressure tube. Because of the increased coolant density (due to its lower temperature) the amount of radiolytic gas formed exceeds the steady-state value but not the design capacity of the recombiner.

5.3 LOOP SHUTDOWN

Loop shutdown is defined as the sequence of operations which brings the Supercritical Loop from steady-state operation or hot standby to cold shutdown for maintenance or refueling. Any shutdown of the reactor necessitates a concurrent Supercritical Loop shutdown.

Prior to the initiation of reactor plant shutdown, the Supercritical Loop is brought to a hot standby condition. As reactor power is reduced, the flow control is set to maintain a constant flow rate through the pressure tube. This constant flow is maintained during the reactor cooldown procedure. Since the heat removal capacity of the Supercritical Loop exceeds the residual heat generation in the supercritical fuel assembly, the Loop coolant stream may also remove heat from the reactor coolant.

During the shutdown operation, makeup water is automatically added to the head tank to compensate for the reduction in Loop water volume as temperatures are reduced. Gas removal operations continue until the Loop is depressurized. Although sampling is normally not required during shutdown, individual samples can be taken at the discretion of the operator.

After the Loop is depressurized, the loop pump is shut off and circulation continued by the condensate pumps alone. By periodically stopping these pumps and observing pressure tube coolant temperature, the operator can determine if heat transfer across the pressure tube wall is sufficient to remove supercritical fuel residual heat. When this condition is attained, the condensate pumps are stopped and maintenance operations can begin.

5.4 REFUELING AND MAINTENANCE

5.4.1 Refueling

Supercritical Loop refueling operations are carried out with the reactor head in place, the storage well flooded to normal plant refueling level and without removing the pressure tube from the reactor. During refueling the condensate pumps are stopped and the pressure tube is isolated. The emergency condenser is placed in service to remove residual heat until the pressure tube is opened. After the top of the pressure tube has been removed, cooling is provided by natural convection to the storage well water. Because of the small clearances between baffles and fuel assembly, the pressure tube internals are removed as a single unit. During replacement of the pressure tube internals, the tube becomes filled with borated refueling water. When the pressure tube is reclosed, this water is flushed out by manually closing the deaerator level control valve (downstream of the filter) opening the drain valve to waste disposal and operating the loop pump until one system volume has been discharged, or until sampling indicates a sufficiently low boron concentration. The pump draws water from the head tank during this operation.

Removal of the entire pressure tube follows essentially the same procedure described above. Fuel element cooling by the emergency condenser is terminated when the pressure tube piping disconnects are opened.

5.4.2 Cleanup and Decontamination

Supercritical Loop coolant activity results in shutdown radiation levels which may exceed the permissible levels for the Saxton Plant. Cleanup and decontamination operations reduce shutdown radiation levels below the maximum levels prescribed for the main plant. The magnitude of the operations involved depends on the mechanical condition of the fuel assembly prior to shutdown.

If no fuel element defects have occurred, the Loop coolant activity will be negligible. The activity will be due primarily to corrosion products, which are removed in the demineralizer during post-shutdown circulation. For this case, coolant activity levels should not exceed 10^{-4} micro-curries/cc ($\mu\text{c/cc}$).

If one or more fuel elements are defective, but no gross failures have occurred, the coolant activity should be less than $5 \mu\text{c/cc}$. Circulation through the demineralizer at a rate of at least 2 gpm for a period of 4 hours will reduce this amount of activity to a tolerable level. During the circulation process, demineralizer influent and effluent streams are periodically sampled and a decontamination factor (DF) determined by taking the ratio of inlet to outlet activity. If the DF falls to unity (no reduction in activity by the demineralizer) the demineralizer is flushed and refilled with fresh resin.

If a gross fuel element failure has occurred, coolant activity levels are several orders of magnitude greater than for defective fuel elements. Under these conditions, additional operations are required to reduce activity to a tolerable level.

The first stage of cleanup is circulation of Loop coolant at a minimum of 2 gpm, with the deaerator and demineralizer in operation. Demineralizer samples are taken periodically to determine the decontamination factor. If the DF falls to unity, either the demineralizer has removed

all the activity it can or it has become saturated. At this time, the flow is temporarily stopped and a resin sample is taken and analyzed. If the sample shows the bed to be unsaturated, the circulation phase is ended. If the bed is saturated, it must be flushed and refilled with fresh resin (Section 5.4.3). Circulation then resumes until it can be conclusively established, using the above methods, that all ionic impurities have been removed. During the circulation operation, the pressure tube is isolated and the loop bypass valve is open.

A gross fuel failure could result in plugging of the pressure tube, making circulation or flushing of the tube impossible. If such a failure takes place, the pressure tube bypass valve will automatically open to provide a flow path around the pressure tube. If it remains closed, the loop bypass valve is opened to permit cleanup of the remainder of the loop prior to pressure tube cleanup.

Following circulation through the demineralizer, a radiation survey is made and radiation levels due to supercritical loop activity determined. If these levels are below those due to main plant activity, the cleanup operation is completed. If the levels are still too high, decontamination is required to remove deposited activity.

Loop decontamination begins with the preparation of suitable decontamination solutions in the feed tank. Prior to filling the loop with solution, the demineralizers are isolated by opening the bypass valve and closing the outlet stop valves. In addition, the pressure tube isolation and loop bypass valves are positioned to divert flow around the pressure tube. Decontamination solution can be added to the loop in two ways; either by setting up drain and isolation valves as for flushing and operating the loop pump until slightly more than one system volume has been discharged (Section 5.4.1), or by draining the system and then refilling by gravity flow from the feed tank.

When the Loop is filled, the bypass around the loop pumps and standby pump is opened, the pumps stopped and the two condensate pumps started. Circulation continues until chemical analysis of the solution indicates satisfactory decontamination. The solution is drained to waste disposal and the Loop is again flushed to remove all remaining decontaminants. At the completion of this operation, the Loop is ready for maintenance.

5.4.3 Demineralizer Resin Removal and Addition

Demineralizer resin replacement operations are performed during shutdown and are, for the most part, controlled remotely. The first step in this operation consists of backflushing to loosen and break up the resin bed, which becomes packed during normal operation. Demineralized water is flushed through the filter bypass valve into the demineralizer outlet line, up past the bed and out through a drain line to waste disposal. After this step is completed, the stop valve downstream of the filter and the filter bypass valve are closed, the resin sluice valve opened and the condensate pumps started to force the resin out to the spent resin storage tanks. Makeup water for the Loop is provided from the head tank by gravity flow. When demineralizer samples indicate that all resin has been flushed out, the sluice valve is closed. The resin fill operation, which follows, is performed locally. First a temporary fill line is connected to the demineralizer from a fresh resin supply. The fill valve is opened, using an extension stem passing through the local shielding, and a measured amount of resin added. Excess water flows through the filter to waste disposal. Finally, the fill valve is closed, the connection removed and the fill line closure replaced. The bed is ready for further operation as soon as the outlet and inlet valves are opened.

Filter cartridge replacement may be carried out following demineralizer resin replacement, if necessary. The filter bypass and outlet valves are closed and the drain valve opened. After the filter vessel has been drained, it is opened and the cartridge removed and placed in a suitable container. A fresh cartridge is then installed and the vessel closed. Opening the appropriate valves restores the unit to service.

5.5 EMERGENCY OPERATION

5.5.1 Loss of Coolant Flow

Loss of coolant flow results from a malfunction or shutdown of the loop pump due to a manual or automatic tripout, mechanical failure, excessive leakage through packing or power failure. On the basis of required corrective action, two types of loss-of-flow accidents have been defined, as follows:

a. Control A

Partial loss of coolant flow is defined as a reduction in measured flow to less than 80%, but not less than 50%, of the loop flow control set-point at the time of the accident.

b. Controls B and C

Complete loss of coolant flow is defined as a reduction in measured flow to less than 50% of the loop flow control set-point at the time of the accident.

A partial loss of coolant flow condition will result in automatic shutoff of the heater and startup of the standby pump. This results in a flow rate of about 12.5 gpm. If continuation of the experiment is desired, the faulty loop pump is removed from service with the required flow provided by the second loop pump.

A complete loss of coolant flow will result in reactor scram and automatic injection of water from the coolant reservoir, in addition to the automatic actions initiated by a partial loss of flow. Following these actions, the loop is brought to hot standby conditions until a decision is reached on the continuation of operations.

5.5.2 Loss of Electrical Power

Loss of electrical power to the Supercritical Loop results in essentially the same automatic actions as a complete loss of coolant flow. Critical portions of the loop load will continue to draw power from the Saxton Plant Electrical System, so that vital control functions and fuel element cooling remain available. If all plant power is lost, injection of water from the coolant reservoir and operation of the emergency condenser will provide fuel element cooling. However, a total loss of power is not considered credible, in view of the reliability of the Saxton Plant power supplies. Following a loss of power, the loop is maintained at hot standby conditions until the power supply is restored.

5.5.3 Loss of Coolant

Loss of coolant would result from the rupture of a pipe or component in the Supercritical Loop process stream. Corrective actions taken depend on the location of the break.

If the rupture is between the loop pump and the pressure tube inlet, reactor scram is automatically initiated by a reversal of pressure differential across the pressure tube. Injection of water from the coolant reservoir into the pressure tube outlet line begins on the same signal. When the coolant reservoir is empty, makeup water from the service water supply is used to make up any further losses through the break. For ruptures downstream of the pressure tube, the reduction in pressure tube inlet pressure automatically scrams the reactor. Continued operation of the loop pump cools the fuel assembly. After the fuel element power has decayed, operation of the condensate pump or pumps or gravity flow from the head tank is sufficient to cool the element.

6.0 LOOP DESIGN AND OPERATING PARAMETERS

6.1 GENERAL

Loop design life, years	5
Total heat transferred from fuel assembly (max.)	3.9×10^5 Btu/hr(115 KW)
Coolant flow rate (nominal maximum)	6750 lb/hr
System volume, total (includes full head tank and full deaerator)	245 gal
System volume, normal operation (excluding head tank)	80 gal
Nominal heating and cooling rate	20°F/min

6.1.1 Supercritical Pressure Operation

Pressure tube inlet pressure (initial pressure tube)	3600 psig
Coolant temperature leaving pressure tube at full power (nominal maximum)	1000°F
Coolant temperature entering pressure tube at full power (1000°F outlet)	967°F

6.2 COMPONENTS

6.2.1 Heat Exchangers

	No. of Units	Exchanger Side	Pressure psig	Temperature °F	Design Fouling Factor hr-ft ² °F/Btu	Flow Rates lb/hr	Temperatures, °F at Design Conditions		Estimates Pressure Drop psi	Heat Load, Design Conditions Btu/hr
							In	Out		
a. Interchanger	1	shell	4400	1030	.0004	6750	130	755	17	6.50×10^6
		tube	600 external	1030		6750	1000	460	38	
b. High Pressure Cooler	1	shell	150	200	0.0006	27,800	100	170	20	1.95×10^6
		tube	4400	750		6750	460	180	93	
c. Low Pressure Cooler	1	shell	150	200	0.0006	22,400	100	120	15	0.40×10^6
		tube	1000	550		6750	190	130	97	
d. Emergency Condenser	1	shell	15	250	-	20	100	212	negligible	1.60×10^4
		tube	4400	1000		variable	300	300	0	
e. Sample Cooler (per unit)	3	shell	150	300	0.0006	1000	100	115	5	1.33×10^4
		tube	4500	1000		10	1000	130	negligible	
f. Vacuum Pump Seal Water Cooler	1	shell	150	200	-	2500	100	102	10	4.1×10^3
		tube	15 psia external	200		1750	107.5	105	1	
g. Reactor Bleed Cooler	1	tube	2500	750	-	500	585	200	-	2.1×10^5
h. Recombiner Condenser	1	shell	150	200	-	2500	102	103		7.6×10^2
		tube	75 psia	1200		12 scfh steam	1100	130	0.5	

6.2.2 Pumps

	No. of Units	Pressure psig	Temperature °F	Design Flow Rate gpm	Developed Head at Design Flow feet	Temperature of Pumped Fluid, °F	Minimum Available NPSH, feet
a. Loop Pump	2	5500	200	15	*	130	45
b. Standby Loop Pump	1	5500	200	5.5	*	130	45
c. Condensate Pumps	2	150 internal 15 external	300	14	135	130	12
d. Ammonia Injection Pumps	2	150	200	0.004	**	80	
e. Pump Leakoff Drain Tank Pump	1	150	200	1.5	65	130	-6

*Positive displacement pumps; maximum required head approximately 11,000 feet

**Positive displacement pumps; maximum required head approximately 135 feet

6.2.3 Relief Valves

	Fluid Discharged	Temperature of Inlet Fluid °F	Set Pressure psig	Capacity
a. PSV-1, Main Safety Valve	Steam	1000	3850	5500 lb/hr
b. PSV-2, Main Safety Valve	Steam	1000	3900	5500 lb/hr
c. PSV-3, Pump Relief Valve	Water	160	4750	11,000 lb/hr
d. PSV-4, Compressor Relief Valve	Nitrogen	500 (max.)	5000	0.02 cfm
e. PSV-5, Service Water System Relief Valve	Water	130	200	3000 lb/hr
f. PSV-6, Cooling Water Relief Valve	Water	366 (max.) ⁽¹⁾	150	1500 lb/hr
g. PSV-7, Recombiner Relief	Steam	310	60	10 lb/hr
h. PSV-8, 9, 10, Sampling	Water	130	150	10 lb/hr

(PSV-8-100)

(1) Actual temperature depends on volume of cooling water contained in piping and components between isolation valves.

6.2.4 Rupture Discs

Location	Fluid Discharged	Temperature of Inlet Fluid °F	Set Pressure psig	Capacity
a. Deaerator, RD-1	Steam	281	50	6500 lb/hr
b. Low-Pressure Cooler, RD-2	Steam at 40% quality	545	1000	11,000 lb/hr*

* 4500 lb/hr of saturated steam and 6500 lb/hr of saturated water.

6.2.5 Heater

Design pressure (pipe)	4400 psig
Design temperature (pipe)	1030°F
Design flow rate, total	6750 lb/hr
Maximum power, total	652.5 KW
Number of identical paths	3
Maximum fluid temperature (at maximum power and design flow)	1015°F
Fluid temperature at heater inlet**	760°F
Fluid temperature at heater outlet**	975°F
Estimated pressure drop (at design conditions)	30 psi
Number of heater elements per path	14
Total number of heater rods	42
Heater rod length	10 ft.

6.2.6 Pressure Tube

Design pressure, internal (initial unit)	4000 psig
Design pressure, external	2500 psig
Design temperature	675°F (lower section), 1000°F (upper section)
Operating pressure, internal	3600 psig

** For 115 KW fuel assembly, 1000°F pressure tube outlet temperature and 6750 lb/hr flow.

O. D. (Lower section)	2.75 in.
I. D. (Lower section)	2.03 in.
Heat leakage through lower portion of pressure tube - inactive core	25,000 Btu/hr
Heat leakage through upper portion of pressure tube including head penetration nozzle cooling	141,000 Btu/hr

6.2.7 Deaerator

Design pressure, internal	85 psig
Design pressure, external	15 psig
Design temperature	330°F
Operating pressure	2.2 psia
Operating temperature	130°F
Water volume, flooded	105 gal
Water volume, normal	9 gal
Gas concentration - inlet	20 ppm O ₂ (max.)
outlet	0.1 ppm O ₂

6.2.8 Demineralizer

Type	Flushable
Vessel design pressure	150 psig
Vessel design temperature	200°F
Resin volume	1.7 cu ft
Vessel volume	2.1 cu ft
Bed depth	36 inches
Estimated pressure drop at normal flow	15 psi
Minimum decontamination factor for ions removed	10
Normal operating temperature	130°F
Maximum temperature	140°F
Normal operating pressure	60 psig
Resin type	ILLCO-NR-8 mixed bed ammonium hydroxide form, Nuclear Grade

6.2.9 Filter

Type	Removable Cartridge
Vessel design pressure	150 psig
Vessel design temperature	200°F
Filter mesh size	25 micron, 5 micron
Estimated pressure drop at normal flow (13.7 gpm)	
- Clean	3 psi
- Fouled	10 psi
Normal operating temperature	130°F
Normal operating pressure	40 psig

6.2.10 Specimen Holders

Number	3
Design pressure	4400 psig
Design temperature	1030°F
Maximum outside diameter	1.1" (ID of 1-1/2" XX pipe)
Design velocity over specimens - SH-1	200 ft/sec
- SH-2	20 ft/sec
- SH-3	186 ft/sec
Estimated pressure drop - SH-1	50 psi
- SH-2	5 psi
- SH-3	50 psi

6.2.11 Accumulator

Design pressure	5000 psig
Design temperature	150°F
Total volume	2.5 gal
Operating pressure (nominal)	4000 psig
Operating temperature (nominal)	100°F

6.2.12 Coolant Reservoir

Design pressure	5000 psig
Design temperature	200°F
Total volume	25 gal
Operating pressure (nominal)	4500 psig
Operating temperature (nominal)	100°F

6.2.13 Reservoir Gas Cylinder

Design pressure	5000 psig
Design temperature - minimum	20°F
- maximum	200°F
Total volume	4 gal
Operating pressure	4500 psig
Operating temperature	100°F

6.2.14 Reservoir Refilling Tank

Design pressure	5000 psig
Design temperature	200°F
Total volume	2 gal
Operating pressure (nominal)	4500 psig
Operating temperature (nominal)	100°F

6.2.15 Gas Compressor

Design discharge pressure	5000 psig
Design suction pressure - maximum	2500 psig
- minimum	200 psig
Design temperature	500°F
Capacity (at 4400 psig discharge, 1000 psig, 100°F suction)	0.001 CFM
Air drive requirements	4 - 5 CFM at 80 psi min., 125 psi max.
Operating discharge pressure	4400 psig

6.2.16 Air Compressors

Design discharge pressure - maximum	125 psig
- minimum	110 psig
Design temperature	300°F
Design capacities	12 scfm and 72 scfm
Receiver capacity	60 gal

6.2.17 Vacuum Pump

Design pressure	15 psig
Design temperature	200°F
Capacity (at normal deaerator operating conditions)	5.4 cfm
Inlet pressure	2.2 psia
Discharge pressure (maximum)	2 psig
Operating temperature	130°F

6.2.18 Vacuum Pump Seal Water Reservoir

Design pressure	full vacuum to 5 psig
Design temperature	300°F
Total volume	0.15 cu ft
Auxiliary steam generator heater power	450 watts
Auxiliary steam generator steam flow (min.)	0.26 lb/hr

6.2.19 Catalytic Recombiner Package

Design pressure	60 psig
Design temperature	1200°F
Catalyst bed temperature	1100°F
Design flow rate, total	12 scfh
Pressure drop at design flow	0.8 psi
Electric heater capacity	700 watts
Maximum outlet oxygen content (for stoichiometric quantities at design flow - normally excess oxygen will be used)	1 ppm
Condensate outlet temperature (maximum)	180°F
Cooling water flow (maximum)	5 gpm

6.2.20 Head Tank

Design pressure (minimum)	60 psig
Design temperature	200°F
Total volume	70 gal

Operating pressure (nominal)	10 psig
Operating temperature (nominal)	100°F
Minimum normal water volume	20 gal

6.2.21 Feed Tank

Design pressure	Atmospheric
Design temperature	200°F
Total volume	80 gal
Operating temperature (nominal)	100°F

6.2.22 Sample Ion Exchangers

Number	3
Design pressure	150 psig
Design temperature	200°F
Resin volume	24 cu in
Operating pressure (nominal)	50 psig
Operating temperature	130°F
Maximum temperature	140°F
Resin Type	ILLCO NR-8 Mixed Bed Ammonium Hydroxide Form, Nuclear Grade

6.2.23 Loop Pump Flow Orifice

Design pressure	5500 psig
Design temperature	200°F
Pressure drop (at inlet conditions of 4400 psia, 130°F, 6750 lb/hr)	200 psi

6.2.24 Pump Leakoff Drain Tank

Design pressure	Atmospheric
Design temperature	200°F
Total volume	35 gal
Operating temperature (nominal)	100°F

6.2.25 Ammonia Injection Solution Tanks

Design pressure	Atmospheric
Design temperature	200°F
Total volume	40 gal
Operating temperature (nominal)	100°F

6.2.26 Piping and Valves

Pipe Run	Nominal Size	Design Pressure psig	Design Temperature °F
Loop pump to orifice	1"	5500	200
Orifice to interchanger	1"	4400	200
Intertchanger, shell side	1-1/2"	4400	1000
Intertchanger to heater	1"	4400	800
Heater shell	1-1/2"	4400	1030
Heater to inlet jumper	1-1/2"	4400	1000
Inlet jumper	1-1/2"	4400	1000
Outlet jumper	1-1/2"	4400	1000
Outlet jumper to interchanger*	1-1/2"	4400	1000
Intertchanger to high-pressure cooler	1"	4400	700
Cooler to letdown valve	1"	4400	700
Letdown valve to deaerator	1"	1000	545
Condensate system piping	1"	150	360
Head tank to loop pump	1"	150	360
Loop pump to accumulator	1"	5500	200
Coolant Reservoir to check valves	1/2"	5000	400
Nitrogen gas piping	3/8"	5000	400
Reactor to emergency condenser and return	1"	4400	1000
Piping to main safety valves	1"	4400	1000
Safety injection line (after check valve)	1/2"	4400	800
Vacuum pump suction	2"	0 psia, 150 psig	300
Vacuum pump discharge	1"	150	300
Component cooling water (all)	--	150	300

Valve design conditions are equal to the design conditions of the pipe run in which the valve is located.

* Previously installed

6.3 INSTRUMENTATION AND CONTROL

6.3.1 Temperature

Instrument Number	Location	Range °F	Normal Reading °F	Set Point		Accuracy %
				Alarm °F	Controller °F	
TR-X1-1 to 11 TR	Fuel assembly inlet and outlet	0-1500	-	TA-X22 A,B	-	+ 6°
TR-X1-12 TR	Pressure tube adaptor nozzle	0-1500	600	TA-X30	-	+ 6°
TR-X1-13 TR	Interchanger hot leg inlet	0-1500	1000 ⁽¹⁾	-	-	+ 6°
TR-X1-14 TR	Interchanger cold leg outlet	0-1500	755 ⁽¹⁾	-	-	+ 6°
TR-X1-15 TR	Interchanger hot leg outlet	0-1500	460 ⁽¹⁾	-	-	+ 6°
TR-X1-16 TR	Reactor head bleed line	0-1500	585	-	-	+ 6°
TR-X2-1 to 3 TR	Sample lines	0-300	130	-	-	+ 5°
TR-X2-4 TR	Interchanger cold leg inlet	0-300	130	-	-	+ 6°
TR-X2-5 TR	Cooling water line to Loop	0-300	70-100	-	-	+ 5°
TR-X2-6 TR	Condensate pump discharge	0-300	130	TA-X12	-	+ 5°
TR-X2-7 TR	Cooling water line from Loop	0-300	150 ⁽¹⁾	-	-	+ 5°
TR-X2-8 TR	Loop safety valve outlet (PSV-1)	0-300	100	-	-	+ 5°
TR-X2-9 TR	Loop safety valve outlet (PSV-2)	0-300	100	-	-	+ 5°
TR-X2-10 TR	Safety injection line	0-300	-	-	-	+ 5°
TR-X2-11 TR	Collection header	0-300	130	-	-	+ 5°
TR-X2-12 TR	Reactor head bleed line	0-300	200	-	-	+ 5°
TR-X2-13 TR	Seal water cooler outlet	0-300	105	-	-	+ 5°
TR-X2-14 TR	Seal water reservoir	0-300	108	-	-	+ 5°
TR-X2-15 TR	Recombiner condenser condensate line	0-300	130	-	-	+ 5°
TR-X2-16, a,b TR	Recombiner inlet and outlet	0-1500	250-500	-	-	-

6.3.1 Temperature (Cont'd)

Instrument Number	Location	Range °F	Normal Reading °F	Set Point		Accuracy %
				Alarm °F	Controller °F	
TR-X3TR	Pressure tube inlet	700-1100 ⁽²⁾	967 ⁽¹⁾	-	-	+ 4°
TRC-X4TR	Pressure tube outlet	700-1100 ⁽²⁾	1000 ⁽¹⁾	TA-X19	1000 ⁽¹⁾	+ 4°
TRC-X9TE	Heater outlet	0-500 and 500-1050 ⁽³⁾	975 ⁽¹⁾	-	975 ⁽¹⁾	+ 2.5°
TRC-X10TE	Heater inlet	0-500 and 500-1050 ⁽³⁾	755 ⁽¹⁾	-	-	+ 2.5°
TRC-X11TR	High pressure cooler outlet	0-300	180	TA-X20	180	+ 4°
TA-X12TR	TR-X2-6 alarm	-	-	140	-	-
TRC-X18TR	Low pressure cooler outlet	0-300	130	-	130	+ 4°
TA-X19TR	TRC-X4 alarm	-	-	1050 ⁽¹⁾	-	-
TA-X20TR	TRC-X11 alarm	-	-	190	-	-
TC-X21TE	Seal water cooler outlet	9-150	-	-	105	+ 3°
TA-X22TR	TR-X1 alarm	-	-	1070 ⁽¹⁾	-	-
TA-X23TR A, B, CTR	Heater flow blockage alarm	-	-	1050	-	-
TIC-X24TR	Catalytic Recombiner	0-1200	500	-	250	-
TI-X25TR	Diluent Steam	100-650	-	-	250	-
TA-X30TR	TR-X1-12 alarm	-	-	650	-	-

NOTES: (1) Values for operation at Loop design conditions of 3600 psia pressure tube inlet pressure, 1000°F fuel assembly outlet temperature, 6750 lb/hr flow rate.

(2) Lower ranges of 400-800°F and 100-500°F available through selector switch.

(3) Lower range of 100-600°F available through selector switch.

(4) Values to be specified later.

6.3.2 Heat Content and Power

Instrument Number	Location	Range	Normal Reading psig	<u>Set Point</u>		Accuracy %
				Alarm °F	Controller °F	
QC-X1	Heater control	0-650 KW	-	-	Variable	+ - 1
QRC-X3	Heater electrical supply	0-650 KW	615 ⁽¹⁾	-	-	+ - 2

NOTE: (1) Values for operation at Loop design conditions of 3600 psia pressure tube inlet pressure, 1000°F fuel assembly outlet temperature, 6750 lb/hr flow rate.

6.3.3 Pressure

Instrument Number	Location	Range psig	Normal Reading psig	Set Point		Accuracy psi
				Alarm psig	Controller psig	
PR-X2	Accumulator gas line	1500-4500	4100 ⁽¹⁾	-	-	+ 15
PA-X3	PRC-X6 high pressure alarm	-	-	4000 ⁽¹⁾	-	-
ΔPRC-X4	Between pressure tube inlet and outlet (pressure differential)	-100 to 300 ⁽²⁾	140 ⁽¹⁾	PA-X5	-10 ⁽²⁾	+ 2
ΔPA-X5	ΔPRC-X4 reverse flow alarm	-	-	-10 ⁽²⁾	-	-
PRC-X6	Pressure tube inlet	0-5000	3600 ⁽¹⁾	High PA-X3 Low PA-X7	3700 ⁽¹⁾	+ 50
PA-X7	PRC-X6 low pressure alarm	-	-	2200 ⁽¹⁾	-	-
PA-X8	PRC-22 high pressure alarm	-	-	5 psia	-	-
PC-X10	Compressor outlet	3000-5000	-	PA-X13	4400	+ 25
PI-X11	Gas cylinder inlet	0-5000	4400	-	-	+ 25
PA-X12	PC-14 low pressure alarm	-	-	3300 ⁽¹⁾	-	-
PA-X13	PC-10 low pressure alarm	-	-	4000 ⁽¹⁾	-	-
PC-X14	Pressure tube outlet	2000-4500	3460 ⁽¹⁾	PA-X12	-	-
PR-X20	Loop pump discharge	2000-5000	4000 ⁽¹⁾	-	-	+ 15
PRC-X22	Deaerator shell	0-20 psia	2.3 psia	PA-X8	1	+ 0.5

NOTES: (1) Values for operation at Loop design conditions of 3600 psia pressure tube inlet pressure, 1000°F fuel assembly outlet temperature, 6750 lb/hr flow rate.

(2) Instrument is designed to measure pressure differential for both normal and reverse flow conditions. Positive readings signify a higher pressure at the pressure tube inlet (normal flow) and negative readings signify a higher pressure at the outlet (reverse flow).

6.3.3 Pressure (Cont'd)

Instrument Number	Location	Range psig	Normal Reading psig	Set Point		Accuracy psi
				Alarm psig	Controller psig	
PI-X23	Between interchanger shell inlet and tube outlet (pressure differential)	0-700	500 ⁽¹⁾	PA-X26	-	+ 15
PI-X24	Condensate pump discharge	0-250	110	-	-	+ 8
PI-X25	High pressure cooler outlet	0-4000	3250 ⁽¹⁾	-	-	+ 25
PA-X26	PI-X23 alarm	-	-	550	-	-
ΔPC-X26	Between pressure tube inlet and outlet (pressure differential)	200-700	-	-	300	+ 25
ΔPC-X28	Between pressure tube inlet and outlet (pressure differential)	200-700	-	PA-X29	500	+ 25
ΔPA-X29	PA-X28 high ΔP alarm	-	-	400	-	-
ΔPC-X30	Between filter inlet and outlet (pressure differential)	5-15	-	PA-X31	-	+ 0.5
ΔPA-X31	PC-X30 high ΔP alarm	-	-	10	-	-
PI-X32	Sample pressure	0-1000	100	-	-	-
PI-X34	Nitrogen pressure	0-3000	2000	-	-	+ 25
PA-X33, PC-X33	Heater Blower	0.15-1.9 in. w.c.	0.16 in. w.c.	-	-	-
PA-X50	Instrument air	0-150	100	75	-	+ 8
PI-X60	Recombiner airfeed	0-60	(2)	-	-	-

NOTE: (1) Values for operation at Loop design conditions of 3600 psia pressure tube inlet pressure, 1000°F fuel assembly outlet temperature, 6750 lb/hr flow rate.

(2) To be determined during initial loop operation.

6.3.4 Level

Instrument Number	Location	Range inches	Normal Reading inches	Set Point		Accuracy inches
				Alarm inches	Controller inches	
LIC-X1	Head tank	0-45	5-17 (20-40 gal)	-	Open valve 5 Close valve 17	± 1.5
LC-X2	Emergency condenser	2 ⁽²⁾	-	-	Open valve 25 Close valve 27	-
LIC-X3	Deaerator	0-14	5	-	Proportional	± 0.5
LI-X4	Loop vent line	(3)	Level above probe	-	-	-
LIC-X6	Coolant reservoir	0-170	164	LA-X7	6	± 5
LA-X7	LIC-X6 low level alarm	-	-	15	-	-
LC-X8	Deaerator	(3)	Level above probe	LA-X9	8	-
LA-X9	LC-8 high water level alarm	-	-	8	-	-
LIC-X10	Seal water reservoir	0-30	-	-	Open valve 14 Close valve 10	± 1
LC-X13	Pump leakoff drain tank	6 ⁽²⁾	-	-	Start drain pump	-
LI-X80,81	Ammonia injection solution tanks	-	-	-	-	-

NOTES: (1) Values for operation at Loop design conditions of 3600 psia pressure tube inlet pressure, 1000°F fuel assembly outlet temperature, 6750 lb/hr flow rate.

(2) Represents distance between probes.

(3) Instruments are single-point level probes.

6.3.5 Flow

Instrument Number	Location	Range gpm	Normal Reading gpm	Set Point		Accuracy gpm
				Alarm gpm	Controller gpm	
FRC-X1	Loop pump discharge	0-20	13.7 ⁽¹⁾	FA-X2, FA-X7	13.7 ⁽¹⁾	+ 0.5
FA-X2	FRC-1, partial loss of flow alarm	-	-	11.0 ⁽¹⁾⁽²⁾	-	-
FIC-X3	Safety injection line	0-20	10	-	10	+ 1.0
FA-X7	FRC-1, complete loss of flow alarm	-	-	6.8 ⁽¹⁾⁽²⁾	-	-
FR-X8	Makeup water line	0-30	-	-	-	+ 1.5
FIC-X9	Reactor head bleed line	0-3	1	-	1.0	+ 0.1
FI-X10	Packing leakoff lines on	0-0.33	-	-	-	+ 0.1
FA-X10	loop and standby pumps	-	-	.15	-	-
FR-X15	Sample ion exchanger 1 inlet	0-0.05	0.033	-	0.02	+ 0.0
FR-X16	Sample ion exchanger 2 inlet	0-0.05	0.033	-	0.02	+ 0.0
FR-X17	Sample ion exchanger 3 inlet	0-0.05	0.033	-	0.02	+ 0.0
FI-X18	Sample lines S-4, S-5, S-6	0-1.5	0.6	-	-	-
FA-X9	Bleed cooler low flow alarm	-	-	0.5	-	-
FI-X26	Recombiner air feed	-	(3)	-	-	-

NOTES: (1) Values for operation at Loop design conditions of 3600 psia pressure tube inlet pressure, 1000°F fuel assembly outlet temperature, 6750 lb/hr flow rate.

(2) Partial loss of flow alarm is set at 80% of nominal flow. Complete loss of flow alarm is set at 50% of nominal flow. Nominal flow for a particular experiment is specified before beginning the test.

(3) To be determined during initial loop operation.

6.3.6 Radiation

Instrument Number	Location	Range mr/hr	Normal Reading	Set Point		Accuracy % of full scale
				Alarm	Controller	
RIC-X1	Condensate pump discharge	0.4-400	(1)	RA-X2	-	+ 6
RA-X2	RIC-X1 alarm	-	-	(1)	-	-

6.3.7 Conductivity

Instrument Number	Location	Range $\mu\text{mho}/\text{cm}$	Normal Reading	Set Point		Accuracy % of full scale
				Alarm	Controller	
CI-X1	Sample S-3 line	0 - 50	(1)	-	-	-

NOTE: (1) To be determined after initial Loop operation.

6.3.8 Control Valves*

	Location	Design Pressure psig	Design Temp. °F	Design Flow gpm	Pressure Drop at Design Flow psi	Fluid Temp. °F	ΔP Closed psi	Position After Failure of Actuating Force
TRC-X9V	Interchanger bypass	5500	150	15	25	150	25	closed
TRC-X11V	High pressure cooler-cooling water outlet	150	200	50	10	170	50	open
TRC-X18V	Low pressure cooler-cooling water outlet	150	200	50	10	170	50	open
TC-X21V	Recombiner condenser cooling water outlet	150	200	5	3	125	50	open
PRC-X6V	High pressure cooler outlet	4500	650	15	3700	180	4500	open
PC-X28V	Pressure tube bypass line	4400	1000	15	200	1000	500	closed
LIC-X1V	Head tank makeup line	150	100	-	50	100	50	closed
LC-X2V	Emergency condenser makeup line	150	100	-	45	100	50	open
LIC-X3V	Loop pump suction	150	150	15	15	130	100	open
LIC-X6V	Coolant reservoir makeup line	5500	150	15	-	100	5000	open
LC-X8V	Vacuum pump suction	150	150	15 cfm	0.2	130	50	open
LIC-X10V	Seal water reservoir drain line	50	200	0.5	13	130	15	closed
FRC-X1V _a	Coolant reservoir discharge	5500	150	15	15	100	5000	open
FRC-X1V _b	Loop pump bypass	5500	150	10	4200	150	4200	closed
FIC-X3V	Safety injection line	5000	100	10	480	100	4500	closed
FIC-X9V	Reactor head bleed line	2500	250	1	1900	200	2000	open

* Remotely operated manual valves (HC) not included.

7.0 FINAL STATUS OF LOOP CONSTRUCTION AND SHAKEDOWN

7.1 GENERAL

Installation of loop components in the Saxton reactor vapor container began on October 15, 1964, and continued for twelve working days. Work was halted to resume scheduled reactor operation. Loop installation was resumed on January 25, 1965, and continued until the program was suspended on April 15, 1965.

Work progressed slower than the established schedules during the second phase of installation (January 25 through April 15, 1965). Construction forces were kept at a maximum level on an accelerated schedule of generally ten hours per day, six days a week. The construction contractors were released on March 27, 1965, and the few remaining construction items were being completed by Westinghouse technicians concurrently with loop shakedown.

"A Pictorial Presentation of the Saxton Supercritical Loop" is included in Appendix A. A brief description of the loop and the placement of components within the vapor container is included, in addition to a graphic presentation of all major loop systems.

7.2 LOOP ERECTION

Mechanical Erection

The mechanical installation work was performed with a force which averaged six fitters and four welders. Other work which was included in Mechanical Contractor's scope was weld testing (radiograph and dye-check), rigging in of prefabricated packages and other large components (primarily pumps and compressors), installation of supports and pipe hangers, on-site fabrication of fittings not available commercially, and all construction janitorial work.

Wherever it was possible, piping sections were prefabricated in the on-site, temporary welding shop. Part of this prefab work had been completed prior to this installation phase. Approximately 3200 welds were required during installation. Of this total, approximately one-third of the welds were made in the field welding shop, and the remaining two-thirds were made in the reactor vapor container.

The general sequence of installation was as follows: complete high pressure piping in primary compartment, high pressure piping in Storage Well, high pressure piping in Auxiliary Compartment, Auxiliary System piping in Primary Compartment, instrument air piping in all areas, auxiliary systems in the Auxiliary Compartment.

Electrical

The electrical forces averaged six men plus foreman (peak force - ten men plus foreman). Following was the general sequence of work completion:

- a. Completed yard conduit and cable work.
- b. Placed cables inside C&A Building.
- c. Placed cables inside Vapor Container (partial).
- d. Ran vapor container penetrating cables.
- e. Sealed and tested vapor container penetrations.
- f. Ran cables from vapor container junction boxes to control room.
- g. Placed remaining cable inside vapor container (as devices mounted).
- h. Made terminal connections at Control Boards and at remote devices.
- i. Made preliminary check outs as circuits completed.

No major difficulties were encountered during installation. Following were the principal inconveniences:

- a. Decreases in worker efficiency necessitated by compliance with Health Physics requirements (i.e., lost time in clothes changing, working while wearing gloves, lost time in entering and leaving the vapor container for parts and material, etc.).

- b. The inefficiency of attempting to do electrical work before mechanical work was completed (i.e., running wire to a device before that device actually was mounted). This was necessary in some cases to prevent the electrical work from falling too far behind.

Instrument Calibration

Initial calibrations were begun on a limited basis about February 20, 1965 in conjunction with checkouts of the control board sections. Calibrations were first completed on recorders, indicators, converters, and controllers in the control boards. Calibrations of remote detector and electrical loop checkouts were completed as external wiring was completed.

Since most of the instrumentation components were supplied by the Foxboro Company, the services of Foxboro field technicians were obtained for parts of the calibration work. Two Foxboro technicians were used from March 1st to March 10th, and one technician was recalled for four days additional work from March 15th to March 19th.

The Westinghouse loop operators were used for assistance in the final phases of the calibration work. It was felt that this would help to familiarize the operators with the loop and its instrumentation.

Radiation Protection

Because of the large number of contractor personnel inexperienced in radiation work and the small SNEC staff for radiation protection, Westinghouse provided additional field engineering services in the area of radiation protection.

During the quarter no serious injuries or accidents occurred. Working radiation exposure limits were set at 300 mrem per week and this limit

was not exceeded. Maximum accumulated whole body radiation exposure was about 1200 mrem; average exposure was about 500 mrem per man. No instances of personnel contamination occurred of such a degree as to give rise to suspicion of significant inhalation, ingestion, or absorption of radioactive material.

Special arrangements were made with SNEC, Penelec, and NAVCO radiographers to insure that use of the radiographic source was in compliance with 10CFR Part 20, the regulations of the State of Pennsylvania, the SNEC operating license and the NAVCO by-product license without unduly impeding construction progress or interfering with SNEC and Penelec plant operations.

Protective clothing and equipment was supplied and administered as required without difficulty. Incidental tool reclamation was accomplished as necessary.

Uncompleted Construction Items

Construction items uncompleted at the time of program suspension included:

1. Installation of the second loop pump and standby pump.
2. Completion of the ammonia injection system.
3. Completion of the sample system.
4. Installation of the pump seal leakage system.

None of these items were needed for the first phases of loop shakedown and as a result were being completed on a schedule which would not interfere with shakedown operations.

7.3 LOOP SHAKEDOWN

Shakedown of the loop started approximately three weeks before program suspension. All installed valves have been checked for proper operation. Electrical supply tests are complete except for the heater package. All instruments have been calibrated to the extent possible without a hot-pressurized system. The following hydrostatic tests have been successfully completed:

1. High pressure loop piping at 6600 psi.
2. High pressure gas system at 6600 psi.
3. Reactor bleed cooler system at 3700 psi.
4. Intermediate pressure loop piping at 1500 psi.
5. Low pressure loop piping at 225 psi.
6. Deaerator system at 128 psi.

Water was circulated through the loop at low temperature and pressure. Initial operation of the loop at design temperature and pressure was the next scheduled test at the time of program suspension.

PART III - FUEL ELEMENT DESIGN AND FABRICATION

1.0 FEASIBILITY PROBLEMS

1.1 GENERAL

Each of the supercritical reactor concepts discussed in Part I of this report share essentially the same fuel and chemistry feasibility problems. Although these problems differ somewhat in degree of severity, depending upon the concept selected for development, all concepts will use fuel cladding operating in the plastic range. Furthermore, all will operate in the same supercritical fluid environment, with its attendant problems in water chemistry and corrosion.

1.2 SPECIFIC FEASIBILITY AREAS

The behavior of collapsed fuel clad under irradiation easily constitutes the most important single area in determining the feasibility of the supercritical reactor concepts. For convenience, this area may be considered in two parts: (a) clad behavior and (b) fuel behavior. Since the two inevitably interact upon one another, however, they cannot be entirely divorced.

a. Clad Behavior

Mechanical and thermal strain cycling imposes a major obstacle to establishing the feasibility of a successful collapsed clad fuel element. Since the high coolant pressure intimately collapses the clad upon the fuel, it is subject to strain due to the differences in thermal expansion that occur with every change in power level.* The strain problem is a complex biaxial or triaxial one because the fuel compact expands both radially and axially. Fortunately, applicable data on collapsed clad fuel rods operating at reactor conditions very similar to those in a high temperature supercritical pressure reactor is now being obtained from the AEC superheat program.

* This is true unless coolant pressure balancing proves feasible.

To be judged satisfactory, fuel clad must function reliably under these cyclic conditions for a few dozen full power cycles and for several hundred small load changes during its two to four year stay in the reactor. The degree of required clad integrity thus depends on the reactor cycle being considered. The number of failures tolerable in a direct cycle system would be smaller than for a closed cycle system.

The clad must also be able to operate satisfactorily at temperatures in the range of 1100 to 1300°F. The precise clad temperature is derived from the bulk coolant temperature, flow rate, and the heat fluxes present in the reactor. The cladding material must not experience appreciable corrosion at such conditions and must retain sufficient ductility to allow it to endure a sizeable number of strain cycles. Clad wrinkling precipitated by reactor scrams or other cyclic conditions can significantly reduce the fuel life since it increases the plastic strain range.

Radiation and corrosion effects can also reduce the strain cycle life of cladding materials. These effects, especially where due to corrosion, need to be evaluated further.

The fact that the clad must exist in a radiation environment with integrated neutron dosages greater than 10^{22} nvt imposes additional stringent demands upon clad performance. Materials such as Incoloy 800, the (W) 16-20 alloy, Inconel 625, and other austenitic stainless steels should prove capable of meeting these severe service requirements providing certain water chemistry conditions can be maintained. At this time, however, there has been no composite test of this fuel cladding in-pile under supercritical reactor conditions.

In the special case of the supercritical breeder or high performance converter, fuel burnups of at least 40,000 MWD/MT average will be necessary to achieve fuel cycle costs which are competitive

with conventional water reactors. One potential problem in this area stems from a possible decrease in cladding ductility due to gas bubbles formed at grain boundaries as a result of an (n, α) reaction with boron impurities at temperatures above 1200°F. This problem is inherent in all fast breeder concepts and implies careful control of boron impurities.

Another interrelated clad fuel problem is fuel swelling at high burnups, which could increase the clad's strain range. Furthermore, there will be redistribution of the fuel with burnup. The effect of this phenomena on local cladding strains must be evaluated.

In addition to the reactor environment, an incorrect method of fuel fabrication could adversely affect clad viability. Two possible fabrication methods for collapsed clad are: (1) pelletization with a reduced radial gap between pellet and clad; or (2) vibratory compacted and swaged. Although both methods appear entirely feasible and capable of achieving a ductile clad element, in-pile experience is needed to determine if a valid preference exists.

b. Fuel Behavior

Uranium dioxide (UO_2) provides the preferred fuel for the supercritical reactor concept because of its high degree of chemical compatibility with clad materials and with the supercritical fluid coolant. Sufficient experimental data is already available to reasonably estimate fuel swelling characteristics and fission gas release rates. The redistribution of fuel under irradiation is a phenomena which is not well understood. The fuel fabrication methods, density, and operating conditions, however, need to be optimized in order to minimize the strain problems in the clad. It is entirely probable that reducing the fuel density, below 95 percent T.D., will prove the preferred

route to achieve high burnup supercritical fuel because of its importance in limiting cladding strain. Even with relatively large gas releases, it appears possible to provide adequate fission gas retention chambers at the end of the fuel elements. However, UO_2 densities less than 89 percent will compact further under irradiation, forming clad wrinkles in the process.

It is anticipated that the thermal performance of rod type fuel elements employed in supercritical reactors will be quite similar to those of current water reactors in terms of kilowatts/foot and center temperatures. Thus, the maximum heat generation rate will be in the range of 15-20 kilowatts/foot, with steady state center temperatures in the order of 4100-4700°F.

Water Chemistry and Corrosion Questions as Related to the Fuel

To date, the behavior of supercritical fluid in the presence of ionizing radiation has not been investigated, thus oxygen concentration levels in a supercritical reactor cannot be accurately predicted. However, radiolytic decomposition of the coolant will certainly occur resulting in some level of oxygen concentration. The presence of both higher temperatures and pressures tends to hasten the natural recombination of the hydrogen and oxygen products. Thus it is anticipated that the oxygen levels in a supercritical reactor will be appreciably less than those in a typical boiling water reactor (~ 20 ppm), but will probably be in excess of the conditions encountered in conventional fossil fuel units (~ 50 ppb). The presence and level of oxygen in the coolant is a critical factor in the formation of crud or scale on the fuel element clad; it can greatly accelerate the corrosion rates and apparently plays a contributory role in the stress corrosion phenomena. Consequently, the development of methods for control and suppression of oxygen in the coolant could constitute a key item in the feasibility study. The means contemplated to achieve this goal for closed cycle and direct cycle plants are discussed below.

Radiolysis in the closed cycle reactor can be suppressed and a reducing condition achieved by maintaining a suitable dissolved hydrogen concentration in the coolant. Conventional systems can be utilized for this purpose. The pH of the coolant can also be maintained at levels conducive to low deposition rates by means of NH_3 addition at modest levels of consumption. It is entirely possible that potassium hydroxide may also prove suitable for this purpose.

Suppression of radiolysis and maintenance of reducing conditions in a direct cycle can probably be achieved by the continuous maintenance of about 10 ppm NH_3 in the feedwater. Hydrazine injection, with its demonstrated effectivenesses,⁽⁵⁾ may also be used as an oxygen level control method, if required, in the direct cycle system.

Another aspect of water chemistry control, essential to the supercritical concept, concerns dissolved solids in the coolant. If an appreciable amount of solids exists, some will deposit on the fuel element surface, creating an insulating layer of crud. Such crud can increase clad temperatures by several hundred degrees, increasing the risk of failure. Conventional fossil fuel units have been able to circumvent these deposition problems by the use of ultra pure (less than 50 ppb) feedwater. There is considerable evidence that such purity for a supercritical reactor can be achieved routinely by using conventional demineralization techniques. The actual requirements for the more severe reactor environment, however, remain to be established by in-pile experience. Cladding materials such as Incoloy 800 or a 16 Cr - 20 Ni iron alloy may prove satisfactory since they are highly resistant to the likelihood of stress corrosion from the presence of entrained chlorides and oxygen. In any event, it will probably be desirable to use materials of this type to protect the reactor clad during transient periods of uncontrolled water chemistry which can occur in any operating plant.

2.0 FUEL TEST PROGRAM

2.1 SUMMARY

One seven rod fuel assembly will be irradiated in the Saxton supercritical loop for six weeks, and a second seven rod fuel assembly will be irradiated for twelve weeks.

The purpose of these tests will be to:

1. Shakedown the loop.
2. Provide supercritical water chemistry data.
3. Expose any large-scale adverse clad strain cycling or water chemistry behavior (the strain range is above that anticipated for some of supercritical concepts described in Part I).
4. Provide short-term corrosion data.

These tests will yield essential data in the areas of greatest technical uncertainty at modest cost and will provide the confidence needed to proceed with further development. Due to their abbreviated duration and relatively low specific power, only limited information will be derived in the areas requiring high performance, long duration tests, such as fuel burnup, long term corrosion, and strain cycles. At the very least the information gained will furnish a basis for decision on continuance of development. If additional fuel tests follow, the data obtained during the first tests will provide a valuable basis for the design of a third fuel assembly for irradiation at higher specific power and a considerable longer test duration. Such extended tests are not covered by the scope of the contract.

2.2 FUTURE WORK

If the results of the short term irradiation tests covered under the contract scope, as summarized above, prove encouraging, further testing would be in order. This would involve the design and fabrication of a third fuel assembly,

making use of the experimental data obtained during the short term irradiations. The third assembly would consist of a larger number of fuel rods of smaller diameter. The pressure tube would be moved into the central experimental position of the Saxton reactor so that higher specific powers and heat fluxes could be obtained. The irradiation would continue for a year or more.

The purpose of the test would be to:

1. Provide strain cycling performance data (strain range and number) at conditions representative or more severe than would be encountered in an operating supercritical pressure reactor.
2. Provide fuel data at high burnups.
3. Provide long-term corrosion data.
4. Provide additional water chemistry data.

2.3 FEASIBILITY CRITERIA

Criteria for demonstrating concept feasibility during the short term tests and projected long term tests are summarized in Table III-1. Estimates of performance requirements for two supercritical concepts; (1) A Closed Cycle, Thermal Spectrum Reactor (Supercritical PWR) and (2) a Hardened Spectrum, Direct Cycle Reactor, are included in Table III-1 to provide a basis for the feasibility criteria.

Short Term Tests

It is considered that tentative technical feasibility will have been demonstrated with the in-pile operation fuel under supercritical pressure conditions for a period of approximately 2000 hours. The ~~pressure tube and fuel assembly~~ are shown in Figure III-1. The irradiation will be divided into three test periods. Two fuel assemblies will be irradiated for six weeks each, with the bulk coolant temperature in the range of 950 to 1000°F. One of these fuel assemblies will also be irradiated

TABLE III-1

Supercritical Pressure Reactor Parameters and Feasibility Criteria

Feasibility Item	Short Term Saxton S.C. Loop Tests (Scope of Contract)	Extended Duration Tests in Saxton* S.C. Loop at Higher Power Levels	Closed Cycle, Thermal Spectrum Reactor	Hardened Spectrum, Direct Cycle Reactor
<u>1.0 Fuel Clad Behavior</u>				
1.1 Full Power Strain Cycles Expected	10-20	~ 40	~ 40	~ 30
1.2 Maximum Clad Mean Strain Range, %	0.6 to 0.7	~ 0.6 to 0.9	~ 0.6 to 0.9	~ 0.4 to 0.5
1.3 Clad Temperature, Limit, °F	1250	1250	1100	1200
1.4 Test or Operating Period, Hours	2000	8000	~ 26,000	~ 17,000
<u>2.0 Fuel Behavior</u>				
2.1 Peak Linear Power, kw/ft	6-10	10-18	15-18	12-15
2.2 Maximum Steady State Fuel Temperature, °F	3050	4800	4700	4500
2.3 Fuel Swelling, % Volume Maximum	negl.	< 1.0	< 2.0	< 6.0
2.4 Peak Burnup, MWD/MTU	2300	> 30,000	≥ 45,000	≥ 65,000
<u>3.0 Water Chemistry & Corrosion</u>				
3.1 Primary Coolant O ₂ Control Methods Primary Coolant	Ammonia or Hydra- zine Injection	Preferred Method from Short Term Tests	Hydrogen Over Press- ure or NH ₃ Injection	Ammonia or Hydra- zine Injection
3.2 Primary Coolant O ₂ Concen- tration Limits, PPB Primary Coolant	100	100	100	100
3.3 Primary Coolant Dissolved Solids Control, PPB	50	50	500	50
3.4 Test or Operating Period, Hours	2000	8000	~ 26,000	~ 17,000

*Not included under contract scope

with the bulk coolant temperature passing through the pseudo-critical temperature range (approximately 720°F) within the fuel assembly. Tests performed by (W) under AEC contract AT(30-1)-2948 have shown that crud is more likely to plate out on the cladding at bulk fluid temperatures near the pseudo-critical point. (Approximately 720°F). During these tests, one fuel assembly will incur as many as 20 full power and 50 smaller strain cycles. This test will be sufficient to evaluate the initial short-time effects, and will expose any large-scale adverse strain cycling or water chemistry behavior. The effects of corrosion and crud deposition will also be evaluated under the two operating conditions described above.

More specifically, fuel and clad performance feasibility for these tests will be demonstrated by successful performance under the conditions specified in Table III-1. Feasibility in water chemistry and corrosion areas will be demonstrated by:

1. Successful application of oxygen suppression and dissolved solids control methods;
2. Absence of significant stress corrosion attack after 2000 hours; and
3. Extrapolation of corrosion and crud deposition data to predict clad performance over a 20,000 hour lifetime in a supercritical pressure reactor.

Available experimental evidence indicates that iron-nickel-chromium alloys, subjected to high-temperature aqueous oxidation, corrode at a linear rate after an initial period at a higher rate. At the temperatures of interest, the linear corrosion rate is reached at the end of 500 to 1000 hours. Therefore to extrapolate corrosion data it is desirable to experimentally determine points at the end of 1000 hours (six weeks) and again after the longest period feasible (at least 2000 hours). The irradiation of two fuel assemblies will make it possible to obtain these two points if the same materials are present in each assembly.

The extrapolation of corrosion and crud deposition can be made on the basis of the following assumptions:

- a. The maximum allowable increase in clad temperature due to crud and oxide film buildup is 300°F over a 20,000 hour period.
- b. The corrosion, W, may be approximated by the expression:

$$\Delta W = \Delta W_0 + k \theta^*$$

where

ΔW - descaled weight loss, mg/dm^2

θ - exposure time, hours

ΔW_0 - extrapolated intercept ($t = 0$), mg/dm^2

k - linear rate constant, $\text{mg}/\text{dm}^2 - \text{hr}$

- c. The extrapolated intercept (ΔW_0) is equal to $220 \text{ mg}/\text{dm}^2$ ^{**}.
- d. The thermal conductivity of the oxide film and deposited crud is $0.5 \text{ Btu}/\text{hr-ft-}^\circ\text{F}$.^{***}
- e. The metal-to-system loss rate is assumed to be $0.05 \text{ mg}/\text{dm}^2\text{-hr}$ after the first 2000 hours.
- f. The peak heat flux is $400,000 \text{ Btu}/\text{hr-ft}^2$.
- g. The allowable average metal loss over a 20,000 hr period is 2.2 mils.

*Based on model proposed by W. L. Pearle et al, Reference 10.

**Calculated using the relationship:

$$\Delta W_0 = 48.5 T \exp \left(- \frac{5230}{T} \right)$$

where

T = exposure temperature, $^\circ\text{K}$

This expression is recommended in the reference above for Incoloy 800.

***There is no adequate data available on the conductivity of an oxide film or crud deposition. This value is believed to be conservative and is subject to change on the basis of new data.

Based on these assumptions, a total weight loss (after descaling) of less than 630 mg/dm^2 and/or a crud deposition and oxide film thickness of less than 0.7 mils after 2000 hours of testing will indicate sufficient confidence to proceed with further testing.

It is possible that the fuel assembly cladding will wrinkle during repressurization after the Saxton reactor scrams while the supercritical loop is at full temperature and pressure. Such wrinkling would significantly increase the strain range. As a result, the clad would be subjected to strain ranges greater than that predicted for fuel assemblies for the reactor concepts listed in Table III-1, even though the specific power is lower.

Long Term Tests^{*}

Technical feasibility will be fully established when fuel rods have been irradiated under reactor conditions at peak burnups of 30,000 MWD/MTU or more. Such tests should demonstrate the long-term clad corrosion and strain cycle behavior. In order to obtain sufficient power in the test section to accomplish this goal, the pressure tube will be moved to the central position in the Saxton reactor core.

A new fuel assembly will be designed using experimental results obtained during the short term tests. It will incorporate two coolant passes with a mixing plenum at the bottom of the active section.

A tentative design has been developed based upon the following assumption:

1. The Saxton reactor nuclear characteristics restrict the test assembly power in the central position to 260 KW.

^{*} These tests are not within the scope of Contract AT(30-1)-3374.

2. The assembly is designed so that the rods in the outer coolant pass are subject to conditions representative to the hot channel in a SC-PWR.
3. The fuel rods in the central coolant pass are subject to conditions typical of a higher temperature advanced supercritical reactor concept.

The first coolant pass will contain 6 to 12 fuel rods. The second coolant pass contains 7 fuel rods. Incoming coolant flows downward over the outer region into a mixing plenum at the bottom of the assembly then upward through central section of the assembly, finally exiting from the pressure tube.

The completion of the long term tests should establish complete technical feasibility of supercritical pressure reactor concepts. However, it would not necessarily reduce the technical and financial risks to a level which a reactor manufacturer would commit a large commercial power plant with firm warranties. Construction of a power demonstration reactor or a prototype would probably be necessary to arrive at a firm commercial position.

3.0 SUPERCRITICAL FUEL ASSEMBLY DESCRIPTION

3.1 PHYSICAL AND MECHANICAL DESCRIPTION

The supercritical loop fuel is enriched UO_2 , either sintered in the form of pellets or vibration compacted and swaged. Table III-2 gives fuel rod design parameters. The pellets have dished ends to offset the effects of greater thermal expansion in the center. A void is provided in the upper end plug of each rod to accommodate fission gas buildup. The fuel is clad with seamless and cold drawn type 16-20 stainless steel or Incoloy, with nominal wall thickness of 10.5 mils. The following assumptions are implicit to the clad design calculations: (a) fuel assembly power output is 80 kw; (b) maximum cold diametral gap is 0.001 in. following loading of pellets or swaging of powder; (c) the cladding is very slightly cold worked (maximum of 3%) following swaging or pellet loading. Specifications used for quality control and inspection are the same as those used for procurement of the normal Saxton fuel tubes as well as those for the Yankee and Selni reactors. All cladding receives a 100% ultrasonic inspection.

Seven fuel rods form the fuel assembly, as shown in Figure III-1. One rod is at the center of the assembly with the other six surrounding it. The outer six rods are spiral wrapped with wire 0.05 inch O.D. at a 10-inch pitch; the center rod is not wrapped. The wire wraps separate the fuel rods and promote coolant mixing. The wire is of the same material as the clad which it is on. The fuel assemblies are bolted to the upper grid and bolts tack-welded in place. The rods are slipped into the lower grid, which restricts radial movement while allowing axial expansion.

The rod cluster is contained within three form-fitting hexagonal fuel assembly baffles (D, E and F) in Figure III-1. These baffles cause the inlet flow to enter the fuel assembly at the lower end of the core and minimize regenerative heat transfer. The fuel assembly baffles are welded at the top to the upper grid. The inner baffle F, shaped to provide the proper cross section for flow in the core, is also welded at the bottom to

TABLE III-2
TEST ASSEMBLY CHARACTERISTICS

Maximum Power Level (Design)	115 kwt
Enrichment	21 % for 80 kwt operation ² * for 115 kwt operation ³
Coolant Flow:	
Design	6750 lb/hr
Minimum allowable ¹ at 80 kwt	4500 lb/hr
115 kwt	6750 lb/hr
Mass velocity through fuel assembly at 6750 lb/hr (nominal)	2×10^6 lb/hr-ft ²
Quantity of UO ₂ in the supercritical loop (7 rod assembly)	6.151 kg
Quantity of UO ₂ in the 21 rods removed from the Saxton fuel assembly	12.826 kg
Heat flux at 115 kwt: Maximum	383,000 Btu/hr-ft ²
Average	159,000 Btu/hr-ft ²
Heat transfer surface	2.47 ft ²
Temperature:	
Coolant, fuel assembly outlet maximum at 115 kwt	1000°F
Coolant, inlet to fuel assembly - maximum at 115 kwt	930°F
Coolant, inlet to thimble - maximum at 115 kwt	967°F
Maximum clad surface temperature (clean wall)	1200°F
Pressure tube hot spot temperature ⁴	661°F
Maximum center of fuel temperature	3830°F

-
- (1) Based upon 1200°F maximum clad surface temperatures and 930°F inlet coolant temperature.
- (2) Case chosen for testing. Reactor power is assumed to be 23.5 MWt for calculation of fuel power output.
- (3) Assumed design limits of operation of loop.
- (4) Calculated value for a three-baffle design.
- * To be specified after 80 kw operation.

TABLE III-2 (Cont'd)

Fuel Assembly:

Active rod length	3 ft.
Fuel rod outside diameter	0.450 in.
Wire wrap diameter	0.050 in.
Clad thickness	0.0105 in.
Flow area	0.00337 ft ²
Hydraulic diameter	0.00975 ft
Rods per assembly	7
Rod lattice	0.500 in.
Fuel rod maximum specific power at 115 kw, normal operation	13.2 kw/ft.
Wire wrap pitch	10.0 in.

Fuel Pellet:

Length	0.76 inches maximum
O.D.	0.429 inches

Fuel Stack Expansion:

Center rod	0.67 per cent
Peripheral rods	0.79 per cent

Baffle Insulation:

Number water layers adjacent to thimble	3
Number water layers enclosing hanger tube and fuel assembly	2
Water layer thickness	0.020 in.

Thimble Pressure Drop:

Maximum	140 psi
---------	---------

Hot Channel Factors:

F_Q^T	2.41
F_θ Film rise	1.18
$F_{\Delta H}^T$	1.81

the lower grid. Outer baffles D and E are dimpled for proper positioning, and an interference fit between dimples and baffles produces radial pressure which helps in centering the fuel assembly and prevents thermal bowing and fretting.

With the fuel rods and fuel assembly baffles suspended from it, the upper grid is hung from the outer fuel assembly hanger baffle. There are three fuel assembly hanger baffles. The heavier outer baffle is welded at the top to the spring guide and at the bottom to the upper grid; the inner two are allowed to expand freely at the top. These baffles separate inlet from outlet flow and minimize the regenerative heat exchange between the inlet and outlet water above the core.

The fuel assembly, the fuel assembly baffles, and the fuel assembly hanger baffles are bolted to the pressure tube baffles described in Section 3.4 below. The assembly is fitted into the pressure tube.

The Saxton fuel assembly, into which the pressure tube is inserted, has 21 rods removed, as shown in Figure III-1. Special spring clips with fingers to support the remaining fuel rods are welded to the grid in the opening formed by the removal of the fuel rods. The pressure tube will be inserted into this opening.

Pressure tube, baffle and fuel assembly parts are shown in Figures III-2, III-3 and III-4. The key for the part number is given below. These numbers also correspond with the item numbers in Figure III-1.

1	Pressure Tube Connector Body	16	Baffle "G"
3	Conoseal Clamp and Sleeve	19	Baffle Cap
4	Lower Pressure Tube Body	20	Thermocouple Guide
10	Spring	21	Cap
12	Thermocouple Guide Cap	22	Baffle End Core
13	Gasket Retainer	23	Upper Grid
14	Guide Tube	24	Lower Grid
15	Screw (6 pieces)	25	Thermocouple Support

Figure III-2

Pressure Tube, Baffle and Fuel Assembly
Parts - Upper Section

Figure III-3

Pressure Tube, Baffle and Fuel Assembly
Parts - Mid Section

Figure III-4

Pressure Tube, Baffle and Fuel Assembly
Parts - Lower Section

26	Thermocouple Conduit	38	Baffle "D"
27	Spring Guide	39	Baffle Support
28	Baffle "H"	50	Conoseal Gasket
29	Baffle "J"	52	Conoseal Gasket
30	Baffle "K"	54	Welding Hub
31	Baffle "F"	55	Pipe
32	Baffle "L"	56	Thermocouples
35	Baffle "A"	58	Thermocouples
36	Baffle "C"	59	Exit Shield Plug
37	Baffle "E"	63	Hypodermic Tube Support

Pelleted Rods

A pelleted fuel rod design is shown in Figure III-5. The cladding will rely on the enclosed fuel for support against the coolant pressure. The fabrication method for the pellets will result in a very small diametral gap between the fuel and the clad (0" to 0.001"). Following fabrication, all fuel rods are subjected to external pressure of 3000 psi and increasing temperature up to 700°F prior to installation in the reactor. The purpose of this pressure temperature exposure is to remove any initial gap following fabrication and to insure that the clad is seated firmly against the fuel without wrinkle formation.

Vibratory Compacted and Swaged Rods

The design of the vibratory compacted and swaged fuel rods is shown in Figure III-6. Arc fused UO_2 is vibratory compacted to approximately 83% theoretical density, then swaged to final theoretical density of about 91%. Following fabrication the rods will be subjected to an external test pressure of 4000 psia at room temperature.

3.2 NUCLEAR CHARACTERISTICS

The supercritical pressure tube is installed in the modified Saxton fuel assembly in the location designated by the numeral N-4 in the Saxton core cross section diagram. The supercritical fuel assembly

STP-510	IT	STP-510	STP-510	STP-510
967692		ECN186	ECN157	ECN157
		2 WAS REMOVED FROM GRV 7819 G LEVINE 73044	REWROTE NOTES #8 GAS VENT HOLES (NOTE J) WERE NOT ON	REWROTE NOTES #8 GAS VENT HOLES (NOTE J) WERE NOT ON

NOTES CONTINUED

- L. Max. allowable tensile load in wire for wrapping purposes equals 55 pounds. Tension must be maintained until final weld stacking wire to tube is made.
- M. Wire/clad gap of section A-A not to exceed .002 inches over 2 inches of wire length. Total of 8 inches of gap permitted per rod.
- N. Straightness allowance, .010 in. per foot of length, .03/length.
- O. Indentations in clad less than .005 deep are acceptable at final inspection.
- P. Inscribe with vibratory tool consecutive identification numbers on this surface. Record identification number, fuel wt., metal wt., fuel height all final dimensions marked, and final clad O.D., maximum and minimum, every two inches along length.

[illegible]

NOTES

- A. All cladding to be 100% inspected with all faults recorded. This includes incoming inspection of 1) physical properties, 2) burst properties, 3) dimensions, 4) riddage line indications, 5) ultrasonic, 6) visual inspection of I.D. and O.D., 7) dye check.
- B. Fuel enriched 51 w/o U235.
- C. B's 2, 4, 5, & 9 to have .4695/.4515 O.D. after swaging x .010/.011 wall before swaging. Ovality of O.D. $\pm .001$ based on nom. O.D. The average O.D. at given cross section must be within the O.D. limits. Min. Fuel density to be 91% of theoretical density. B's to be heated by 15 min. at 1850° F in hydrogen and slow cooled prior to final swaging from .460 to .459 O.D. B's to be heated for 15 min. at 1850° F in argon and then cooled prior to final swaging from .460 to .459 O.D.
- D. Trim fuel flat and square within .002. Do not remove any clad material during this operation.
- E. Trim cut L.R. & R's 1 & 8 such that end plugs should be clad and bottom of fuel within .002. Trimmed ends shall be square within .002 ± T.R. C/Bore R's 1 & 8, 13/20 give a give .901 inch dia. with fls. 12 & 13. Press R's 12 & 13 completely into R's 1 & 8. R's 12 & 13 to be flush with R's 1 & 8. Clad ends shall be deburred with a maximum chamfer of 0.002 inches in the inside and outside chambers.
- F. Clad cutoff to be saved and identified with particular fuel rods.
- G. Prior to welding maintenance weldment of entire assembly shall not exceed an amount equivalent to 30 ppm of total fuel weight.
- H. Use procedure outlined by PG 292712 disregarding Para. 1.1, 2.2, 4.3 & 5.5 Change para. 6.6, 7.5 Heat. Porosity dia. $\pm .005$ in.
- I. .4525 maximum diameter after welding. All surfaces in the weld area must have a smooth transition. Caution! No grinding of tube wall permitted. Rolling of welds permitted providing the operation is restricted to the weld zone and does not extend to the final cladding in the fuel region. Rolling procedure to be approved by WAFB.
- J. Fusion weld per CAP 586139 (Sub-A), .02 min. penetration. Grind smooth.
- K. Before wrapping groups 2, 3, 5, 6 & 8, subject groups 1, 2, 3, 4, 5, & 6, to 2000 psi pressure at 700° F for 30 minutes. Reject any rod when clad cracks are observed.

[illegible]

Figure III-6

depends upon neutrons from the Saxton reactor core for generation of its power and therefore behaves as a segment of the core. Power generation in the supercritical loop is dependent on the power level of the Saxton reactor core region adjacent to the pressure tube.

The Saxton reactor reactivity coefficients will be essentially the same with the pressure tube or dummy plug in the core. The reactivity coefficients for the Saxton reactor resulting from moderator variations in the supercritical loop are as follows:

Flooding coefficient	= $5.0 \times 10^{-4} \Delta k/k$ for Saxton reactor with variation of supercritical coolant from 950°F, 3500 psi to 300°F, 100 psi conditions.
Temperature coefficient	= $-1.1 \times 10^{-6} \Delta k/k$ for Saxton reactor per °F supercritical loop average coolant temperature increases.
Pressure coefficient	= $0.25 \times 10^{-6} \Delta k/k$ for Saxton reactor per psi supercritical loop pressure increase.
Density coefficient	= $0.69 \times 10^{-5} \Delta k/k$ for Saxton reactor per per cent supercritical loop coolant density increase.

The power distribution within the supercritical loop fuel was calculated by the PLMG and SLOP-1 digital computer codes.

3.3 THERMAL AND HYDRAULIC CHARACTERISTICS

The thermal and hydraulic characteristics of the supercritical fuel assembly are included in Table III-2. The installation and operation of the supercritical loop does not significantly affect the thermal and hydraulic characteristics of the Saxton reactor core.

There are no DNB considerations in the operation of the supercritical loop at power because the coolant is steam at supercritical conditions. During hot standby operation of the supercritical loop, the loop inlet temperature and operating pressure are approximately the same as that for

the reactor. Under these conditions, the supercritical fuel assembly power will rise above its normal value because of the increase in coolant density. For the 115 kw assemblies, this rise in power will result in a peak specific power lower than the 16 kw/ft which previously has been shown to be safe for the special spiked Saxton assembly in the center of the core. The heat transfer characteristics and physical description of the pressure tube baffles are included in Section 3.4.

3.4 PRESSURE TUBE ASSEMBLY

The pressure tube assembly, shown on Figure III-1, is of the bayonet re-entry type. Coolant at 3600 psig and 600°F to 975°F enters the pressure tube through the lower jumper and flows downward through the annulus formed by the pressure tube baffles and the fuel assembly baffles. At the lower end of the pressure tube, the flow direction is reversed to pass upward through the fuel assembly and inner fuel assembly hanger baffles. The coolant leaves through the top jumper at temperatures up to 1000°F.

A marman Conoseal pipe joint serves to support the pressure tube assembly and prevent leakage of reactor primary coolant. This joint can be serviced by remote maintenance tools. Inlet and exit jumper piping connections are made with Grayloc fittings. A remote maintenance tool is feasible for these fittings and will be used if necessary to limit maintenance personnel exposure. The pressure tube assembly consists of four components; the connector body, pressure tube extension, the head adaptor flange assembly, and the pressure tube, all of AISI Type 316 stainless steel.

The rough machined connector body is welded to the head adaptor male flange. After final machining operations, this assembly is welded to the pressure tube to form the completed pressure tube assembly.

Connector Body

The connector body is designed for 4000 psig and 1000°F with atmospheric pressure outside. A three-inch thickness of insulation is provided. The inlet and outlet nozzles are machined from solid stock as part of the connector body. They are spaced approximately 16 inches apart to reduce heat transfer and thermal stresses between the two areas. A refueling port is located in the upper end of the connector body and is sealed with a Conoseal gasket. A ring and six jack screws, made of W-545 steel, serve to hold the Conoseal male flange in place. Each jack screw is tightened to 95 pound feet torque to preload the Conoseal gasket with sufficient axial compression to resist any gasket movement during operation at 4000 psi. Conoseal clamp and sleeve flange is of AISI Type 316 stainless steel.

Hydrostatic thrust due to 4000 psi internal pressure and the refueling port spring is 26,500 pounds. Axial port stress in the threaded area from this thrust is 2700 psi. Ring thread shear stress is 4500 psi and jack screw bearing stress and thread shear stress are 18,400 psi and 3700 psi respectively. The jack screw bearing stress is equal to 1/2 of the stress required to produce 10% relaxation in 1000 hours in W-545 stainless steel at 1100°F. W-545 was chosen for ring and jack screws because it matches the coefficient of thermal expansion of the refueling port male and female flanges. In addition, it possesses high strength at 1000°F; typical creep rupture stress at 100,000 hours at 1000°F is approximately 80,000 psi.

A ball-cone seal, just below the outlet nozzle, supports the fuel assembly and prevents the bypass of inlet coolant around the fuel assembly to the exit jumper. To secure a positive sealing against hydrostatic pressure, a refueling port spring is provided in the top of the pressure tube assembly which is designed to provide a minimum sealing force of 60 lbs. The spring force is based on the following assumptions:

1. Total thrust due to hydrostatic pressure	- 530 lbs.
2. Weight of internal parts	+ 75 lbs.
3. Buoyant force	- 10 lbs.
4. Baffle friction force	- 125 lbs.
5. Minimum spring force at temperature	<u>+ 650 lbs.</u>
6. Minimum net sealing force	+ 60 lbs.

Head Adapter Flange Assembly

The head adapter flange assembly supports the pressure tube while connecting it to the Saxton reactor head adapter. The head adapter flange assembly screws into the Saxton reactor head adapter and is seal welded. The assembly is welded to the connector tube. The male and female sections of the assembly are joined at the Conoseal joint and clamped together. The assembly parts are constructed of Type 316 stainless steel.

Pressure Tube and Pressure Tube Extension

The portion of the pressure tube assembly extending within the reactor vessel will not be code stamped because it is completely contained within the reactor vessel which is the ultimate container for reactor and loop coolant. This portion, however, is designed to meet the intent of Section VIII of the ASME Pressure Vessel Code as outlined below.

Part II of this report describes normal loop startup, operating, and shutdown conditions. Initially, the loop and reactor are brought to 2000 psi and 530°F together. Differential pressure across the pressure tubes are small during this time. The loop pressure is then increased to 3600 psi normal operating pressure followed by increasing loop temperature to test inlet temperature. The reactor is brought to power. Normal operating conditions have thus been established.

These conditions are: 3600 psi internal pressure and 2000 psi external pressure for a maximum difference in pressure between the inside and outside of the pressure tube of 1600 psi; 675°F pressure tube maximum temperature (including gamma heating) and 600°F pressure tube extension maximum temperature. Reverse procedure is followed during loop and reactor shutdown.

Paragraph UG-21 of ASME Code VIII specifies the following procedure to determine minimum vessel design pressure: "UG-21 DESIGN PRESSURE. Vessels covered by this section of the Code shall be designed for at least the most severe condition of coincident pressure and temperature expected in normal operation. For this condition, the maximum difference in pressure between the inside and outside of a vessel, or between any two chambers of a combination unit, shall be considered (see Paras. UG-98 and UA-60(b))."

The most severe condition of coincident pressure and temperature expected in normal operation is 1600 psi at 675°F in the pressure tube and 600°F in the pressure tube extension. However, for extra conservatism, the following conditions are used for design. The pressure tube extension and the pressure tube are designed to withstand 4000 psig internal pressure and zero external pressure at the above listed temperatures and 2100 psig external pressure and zero internal pressure at the above listed temperatures.

The pressure tube extension wall is based on 2100 psig external pressure at 600°F. Allowable stress for SA 182 Type 316 stainless steel for these conditions is found in Section VIII of the Code to be 15,950 at 600°F. The maximum outside diameter is 2.841 in. and the minimum wall thickness is calculated from Figure UG-31 of Code VIII to be 0.360 inches. The specified minimum wall thickness is 0.379 inches.

The pressure tube wall thickness is based on 2100 psig external pressure at 675°F. Allowable stress for SA 182 Type 316 for these conditions is 15,875 psi at 675°F. The maximum outside diameter is 2.753 inches and the minimum wall thickness is calculated from Figure UG-31 of ASME Code VIII to be 0.350 inches. The minimum specified wall thickness is 0.353 inches.

During fabrication, strict quality control and inspection procedures will be adhered to. All welded joints will be fully radiographed to Code standards. All pressure containing materials will be ultrasonically inspected. Welder and welding procedure qualifications will be based on ASME Code IX.

Following fabrication, the entire pressure tube assembly will be hydrostatically tested in accordance with Paragraph UG 99 of Code VIII. The assembly will be subjected to separate internal and external pressure tests.

Pressure Tube Baffles

The three pressure tube baffles are fabricated from stainless steel sheet metal and are provided to minimize the loss of heat to the Saxton reactor primary coolant and to maintain the pressure tube wall temperature at or below an acceptable value of 675°F. This is achieved by the insulating effect of three 0.020 inch thick layers of stagnant water. The baffle design temperatures are based on 950°F inlet coolant temperature.

The three baffles are fastened to the pressure tube baffle support cylinder at a slip joint, and the support cylinder is welded to the spring guide. The support cylinder has six slots to allow inlet flow access to the downflow channel formed by the pressure tube baffles and the fuel assembly hanger baffles. The lower grid is bolted to the pressure tube baffles.

The dimple interference causes the baffles to deflect radially, thus inducing a radial force on the baffles. This gives rise to a friction force when:

1. One baffle is inserted into another.
2. The baffle assembly is inserted into or pulled out from the pressure tube.
3. One baffle has an expansion relative to the other due to a temperature differential.

It is estimated that for case (1), approximately 400 lb. force will be necessary to overcome the frictional force with an assumed coefficient of friction of 0.2. The maximum stress induced by the process of insertion is 10,000 psi.

In case (2), a maximum frictional force of 115 lb. is developed. As a result, 40 lb. force will be necessary to insert the baffle assembly and 270 lb. force will be needed to pull the baffles out of the pressure tube. The process of removal will induce a maximum axial compressive stress of 1700 psi in the outer baffle.

For case (3), the induced stress ranges up to 13,000 psi. The radial temperature gradient between baffles results in axial differential expansion. Allowance is made for this by bolting all three baffles at the bottom to the fuel assembly and allowing them to expand freely at the top where a slip joint is provided to accommodate the differential expansion. All stress levels are less than yielding and buckling strengths.

Alternate Zircaloy Pressure Tube

The pressure tube design originally incorporated a bimetallic, metallurgically bonded, transition joint used to connect a Zircaloy-4 portion of the pressure tube in the active core region, to an upper stainless steel portion. This joint permits the elimination of complex mechanical devices which require large diametral clearances.

As part of an earlier Westinghouse funded program, six transition joints were purchased from Nuclear Metals Inc. These joints were manufactured by tandem extrusion using a process developed by NMI. One failed inspection after tube reduction, one was burst tested and a third was tension tested after being pressure and temperature cycled.

The other three were welded to Zircaloy tubes; two for fabrication into pressure tubes and the third for further burst testing after cold drawing. One joint was severely damaged while attempting to remove the mandrel after cold drawing. The two remaining transition joints developed small unbonded areas during the drawing operation.

Due to schedule pressures, concern about the unbonded areas in the transition joints and the lack of data on how a joint might perform when subjected to a large number of strain cycles, it was decided that the Zircaloy pressure tubes would be unsatisfactory for use in the program. The referenced, all stainless steel pressure tube design, described above, was adopted. The use of an all stainless steel pressure tube reduces the obtainable power level in the fuel assembly. However, a planned increase in the nominal power level of the Saxton reactor largely compensated for the effect of the stainless steel and it appeared that the nominal design goal of 80 kw was still possible.

A full report on the Zircaloy-stainless steel evaluation is given in a report entitled, "Evaluation of Zircaloy-Stainless Steel Metallurgically Bonded Joints," WCAP-3374-7.

4.0 FUEL ROD DESIGN ANALYSIS

4.1 GENERAL

A major objective of the Supercritical Technology Program is to demonstrate, in a preliminary manner, the technical feasibility of fuel operation in a supercritical environment at cladding strain ranges beyond the elastic limit. The pressure tube containing the fuel assembly is installed in the N-4 experimental location near the periphery of the Saxton reactor core. The lower flux in this position limits the obtainable specific power in a fuel rod to a value well below the peak value necessary for an economic commercial power plant. Comparative fuel design parameters for the STP fuel assembly and two representative supercritical reactor concepts are given in Table III-1 above. In order to obtain a strain range equal or greater than anticipated for an advanced supercritical concept, the STP fuel rod cladding thickness to diameter ratio was fixed at a value below that which would be seriously considered for an actual reactor design.

4.2 DIFFERENTIAL THERMAL EXPANSION

As the fuel rod is subjected to the loop pressure and the temperature is brought up to zero-power conditions, the tensile strain in the clad will be relaxed and converted to a compressive strain by the coolant pressure. As the fuel rod is taken from zero power to full power, the fuel will expand more than the clad, and the clad will be strained in tension. During subsequent cycles, the clad will experience tension and compression straining. The maximum plastic strain range will be approximately 0.21%. For a complete startup and shutdown cycle, the total strain range will be between 0.6 to 0.7%. There are a number of published correlations for low cycle fatigue life, but the combined influence of fracture ductility, biaxial strains and local deformations plus temperature, corrosion and radiation effects are imperfectly understood to say the least. Using the Incoloy strain fatigue correlation and data from reference 11, more than 100 such cycles would be required to cause fatigue failure.

Fuel rod assembly temperatures and strains are given in Table III-3. The strains are approximate mean values due to differential expansion alone and do not include the effects of thermal bowing, discontinuities, wrinkling and other effects.

4.3 CLADDING STABILITY

The formation of wrinkles in the cladding would have an adverse effect on cladding performance. The presence of a large gap between the fuel and cladding could give rise to wrinkling during the initial startup cycle. The maximum diametral clearance between fuel and cladding for the STP fuel rods was specified as 0.001 inch in order to circumvent this problem. However, it is possible that wrinkles could also form under certain transient operating conditions. Such a case will be considered below.

The tendency towards wrinkling is a function of many factors such as the gap between the fuel and cladding, material properties, clad thickness to diameter ratio and system pressure and temperature conditions. The effect of clad thickness as a function of system pressure and temperature is illustrated in Figure III-7. The collapse mode is indicated as a function of temperature and cladding thickness to diameter for an assumed set of material properties. At lower thickness to diameter ratios, the tendency is towards elastic collapse and at higher thickness to diameter ratios, plastic collapse.

For a wrinkle to form there must be a gap between the fuel and cladding regardless of the collapse mode. As an example, consider a clad design with zero gap initially but with t/d_o such as to be potentially subject to elastic collapse. The clad is subjected to external pressure $-P_o$. The clad is supported by fuel reaction pressure $+P_o$. If the cladding expands faster than the fuel, as during zero power heat-up, or the fuel shrinks faster than the cladding, as during shut-down from power, fuel/clad interface pressure will tend to become $P_p - P_o' \sin \theta$ where θ is the angular coordinate measured about the clad axis. The net radial pressure

TABLE III = 3

Temperature and Strain Conditions (No Wrinkles)

Full Power		Hot Stand-by	
q'' , BTU/hr/ft ²	360,000	$\bar{T}_c = \bar{T}_f$	950
K , BTU/hr/ft ² /°F/in.	100	$\alpha_c \bar{T}_c^*$	.0082
$\Delta T_c = q'' t/K$	36	$\alpha_f \bar{T}_f^*$	.0038
T_{ic}	1200		
$T_{oc} = T_{ic} - \Delta T_c$	1164	$\epsilon_{co} = \alpha_c \bar{T}_c^* - \alpha_f \bar{T}_f^*$	.0044
$\bar{T}_c = 1/2 (T_{oc} + T_{ic})$	1182		
q' , kw/ft	9.2	Total Strain Range = $\epsilon_{co} + \epsilon_{cp}$	
h , BTU/hr/ft ² /°F	2000		
$T_{of} = T_{ic} + q''/h$	1380	<u>Nomenclature:</u> <div> T - Temperature q'' - Heat Flux K - Conductivity c - Clad f - Fuel i - Inside Surface </div> <div> o - Outside Surface p - Plastic h - Contact Resistance α - Thermal Expansion Coefficient ϵ - Strain </div>	
T_{cf}	3050		
$\bar{T}_f$	2215		
$\alpha_c \times 10^6$	9.6		
$\alpha_c \bar{T}_c^*$	.0106		
$1/2 \alpha_c \bar{T}_c$	.0002		
$\alpha_f \bar{T}_f^*$	.0125		
$\epsilon_{cp} = \alpha_f \bar{T}_f^* + 1/2 \alpha_c \Delta T_c - \alpha_c \bar{T}_c^*$	.0021		

PLASTIC COLLAPSE: $P_p = 2.31 S_y (t/d_o)$, NO OVALITY AND SMALL t/d_o

ELASTIC COLLAPSE: $P_e = 2(E/1 - \mu^2) (t/d_o)^3$.

INDETERMINANT COLLAPSE: $P_p = P_e$

MATERIAL PROPERTIES FOR 16 Cr - 20 NI ALLOY:

T, °F	70	500	1000	1500
S_y , ksi (MIN)	28.2	19.0	16.5	15.6
E, 10^6 psi	28.5	26.6	23.6	20.4

Figure III-7

Collapse Modes for Cladding

across the clad, $-P'_o \sin \theta$, generates compressive hoop stresses which range between $\frac{\pi}{4} \frac{P'_o R_o}{t}$ and $1/2 \frac{P'_o R_o}{t}$ with an average value of $.64 \frac{P'_o R_o}{t}$. When $P'_o = P_o$ a gap begins to form. However, if $.64 \frac{P_o R_o}{t} \geq$ clad yield strength, the clad will have to deform radially in order to be cold worked to the point where the clad can sustain a stress of $.64 \frac{P_o R_o}{t}$ in a condition of static equilibrium. But there is no radial gap present for the clad to be radially deformed. Therefore, if $.64 \frac{P_o R_o}{t} \geq$ clad yield strength, a gap cannot be formed.

Consider a hypothetical transient case in the Saxton loop where a reactor scram is accompanied by a heater trip-out. A drop of temperature and pressure would follow. A severe drop in loop pressure could result in clad wrinkling as illustrated below:

$$t/d_o = 0.025$$

$$S_y \approx 18,000 \text{ psi (Value for 16 Cr - 20 Ni Stainless Steel)}$$

$$P_o = \frac{18,000 \times 0.050}{0.64} = 1400$$

Thus a system pressure drop to a value in the order of 1400 psi would allow a gap to form. Repressurization would elastically collapse the cladding giving rise to wrinkle formation. A higher strength material, such as Incoloy 800, would be subject to wrinkle formation under less severe transient conditions. However, a higher strength material would have certain advantages, which would include a greater ability to "bridge" small imperfections in the fuel and gaps between pellets without extensive deformation.

4.4 THERMAL BOW

An analysis was performed to determine the rough magnitude of thermal bowing which could be expected in the fuel assembly. The magnitude appears to be small, in the order of 0.002 of an inch. A sample thermal bow calculation is included below:

Definitions for Thermal Bow Analysis

c	distance between modes in bowed rod.
D	hydraulic diameter.
D _o	0.00975 ft.
d	rod diameter = 0.45 in.
G	1.33×10^6 lb/hr-ft ² , minimum flow at 80 KW power.
g	1/2 gap between rods, inches.
h	film coefficient.
q"	2.66×10^5 BTU/hr-ft ² , maximum heat flux at 80 KW power.
T	temperature, °F.
V	flow velocity.
α	5×10^{-6} per °F, fuel thermal coefficient of expansion.
Δg	$\Delta g_m + \Delta g_t$.
Δg_m	initial rod displacement due to mechanical tolerances, inches.
Δg_t	rod displacement due to thermal bow, inches.
θ	$T_W - T_B$
ϕ	θ/θ_o

Subscripts

0	average
1	hot side
2	cold side
B	bulk
W	wall surface

Model for Fuel Rod Flow Channel

$$g_o = 0.025 \text{ inches}$$

Assume Uniform Heat Flux Around Rod Periphery

$$q_1'' = h_1 \theta_1 = q_2'' = h_2 \theta_2 = q_o'' = h_o \theta_o$$

$$\phi_1 = \frac{\theta_1}{\theta_o} = \frac{h_o}{h_1} = \frac{v_o}{v_1} = \left(\frac{D_o}{D_1} \right)^{1/2} = \left(\frac{g_o}{g_o - \Delta g} \right)^{1/2}$$

$$\phi_2 = \frac{\theta_2}{\theta_o} = \frac{h_o}{h_2} = \frac{v_o}{v_2} = \left(\frac{D_o}{D_2} \right)^{1/2} = \left(\frac{g_o}{g_o + \Delta g} \right)^{1/2}$$

Assume Unrestrained Rod Bows into Arc of Circle

$$\frac{\Delta g}{g_o} = \frac{\Delta g_m}{g_o} + \frac{c^2 \alpha \theta_o}{8 d g_o} (\phi_1 - \phi_2)$$

Film Drop vs. Rod Deflection Due to Bow

$$\phi_1 = \left[1 - \frac{\Delta g_m}{g_o} - \frac{c^2 \alpha \theta_o}{8 d g_o} (\phi_1 - \phi_2) \right]^{-1/2}$$

$$\phi_2 = \left[1 + \frac{\Delta g_m}{g_o} + \frac{c^2 \alpha \theta_o}{8 d g_o} (\phi_1 - \phi_2) \right]^{-1/2}$$

Assume End Plugs and Wire Wrap Constrain Center and Outer Rods to Assume This Shape

Nominal Film Drop vs. Nominal Heat Flux (From WAPD-SC-1)

$$q'' D^{0.1} / G^{0.9} = 2.66 \times 10^5 \times 0.00975^{0.1} / (1.33 \times 10^6)^{0.9}$$

$$= 0.5$$

$$T_B = 1000^{\circ}F, T_W = 1130^{\circ}F$$

$$\theta_o = 130^{\circ}F$$

Maximum Surface Temperature, T_{W1}

For: $c = 5"$; $\alpha = 5 \times 10^{-6}/^{\circ}\text{F}$; $\theta_o = 130^{\circ}\text{F}$; $d = 0.45"$;

$$g_o = 0.025"; \Delta g_o = 0.005"; \frac{c^2 \alpha \theta_o}{8 d g_o} = 0.18$$

$$\text{Then: } \phi_1 = (T_{W1} - T_B)/(T_{W0} - T_B) = 1.17$$

$$\phi_2 = 0.80$$

$$T_{W1} = 1000 + 1.17 \times 130 = 1150^{\circ}\text{F}$$

$$T_{W2} = 1000 + 0.80 \times 130 = 1100^{\circ}\text{F}$$

Rod Deflection, Δg_T , Due to Bow

$$\Delta g_T = c^2 \alpha \theta_o (\phi_1 - \phi_2) / 8d = 0.002 \text{ inches}$$

5.0 FUEL DEVELOPMENT AND FABRICATION

5.1 GENERAL

Fuel fabrication development covered investigation of three fabrication techniques using both Incoloy 800 and 16 Cr - 20 Ni stainless steel as a cladding material. The methods included:

1. Pellet loaded fuel rods with small diametral clearances between the pellets and cladding.
2. Vibratory compacted and swaged rods incorporating fused UO_2 .
3. Pressure bonded fuel rods utilizing a technique developed by Battelle Memorial Institute.

Successful techniques were developed for the first two processes utilizing both cladding materials. The third fabrication technique, pressure bonding, was not developed to the point that it could be considered for actual fuel rod fabrication. In addition, it was finally decided not to mix cladding materials in the same fuel assembly nor utilize different fabrication methods for individual rods in a given fuel assembly.

Incoloy 800 clad pelletized fuel rods were selected for the first fuel assembly on the basis of maximum present technology and the fact that similar elements had operated successfully at comparable temperatures and lower pressures. Other reasons for the selection were:

1. There is more information on the short term temperature mechanical properties, creep properties, stress rupture properties, fatigue and corrosion data on the Incoloy 800 alloy.
2. The short term tensile and yield strength properties of Incoloy 800 in the annealed condition are superior to those of 16-20 stainless steel in the same condition. Adequate data is not available to make comparisons of other properties.

3. Although 16-20 has superior weldability, the welding development conducted to date with Incoloy 800 indicates that satisfactory welds can be performed with this material.
4. The use of dished pellets will minimize axial differential expansion and ratcheting.
5. Although test experience indicated that one could expect a bamboo type deformation of the cladding after thermal cycling, the small number of temperature cycles to which this fuel assembly will be subjected should not be a sufficient cause for failure.

It may readily be noted that many of the reasons for recommending the Incoloy 800 in pellet fuel are based on the more advanced state of this fuel as compared to vibratory compacted fuel or 16-20.

A second fuel assembly consisting of vibratory compacted and swaged uranium oxide powder clad in 16-20 stainless steel was selected because of its potential improvement in fuel economics and reliability.

1. 16-20 has a lower neutron cross section than Incoloy.
2. 16-20 is the preferred choice over Incoloy for use with the vibratory compacted and swaged fuel fabrication process because of metallurgical considerations. In order to obtain adequate ductility in the clad an intermediate anneal is necessary in the swaging process for both materials. The annealing process for 16-20 produces no significant grain boundary precipitation.
3. If it is necessary to keep clearances between the fuel and cladding at a minimum, the process may have an economic advantage.
4. Local clad deformations caused by pellet interfaces or thermal distortion of the pellets during transient temperature conditions are eliminated.
5. 16 Cr - 20 Ni has superior weldability.

At the time of the program suspension, one fuel assembly utilizing pellets and Incoloy 800 cladding was complete. A second assembly with vibratory compacted and swaged rods, clad with 16 Cr - 20 Ni stainless steel was 80% complete.

5.2 CLADDING HEAT TREATMENT

A test program was initiated to investigate the mechanical properties of Incoloy and 16-20 tubing subjected to different heat treatments and different degrees of cold work.

Data accumulated during the program indicates that tubing with approximately 10% or greater cold work, without further heat treatment, does not meet the ductility requirements specified for the test fuel assemblies. This applies to both Incoloy 800 and 16-20 stainless steel. Considerable cold work is applied during tube drawing or any later swaging operations on loaded fuel rods.

A minimum of 6% increase in diameter after burst testing at 1000°F is specified for all clad material to be irradiated. It is felt that a burst test is a better quantitative measure of ductility than a uniaxial tensile test, because it more closely represents actual strain conditions expected during reactor operation.

Test data for Incoloy 800 and 16-20 stainless steel is tabulated in Table III-4 and III-5 respectively. The results of metallurgical examination of the two cladding materials after heat treatment is given in Table III-6.

The selected reference heat treatments are as follows:

Pelletized Rods

- Incoloy - 1800°F anneal and quench before loading
- 16-20 - 1350°F anneal for 5 hours after loading

TABLE III-4

MECHANICAL PROPERTIES OF INCOLOY 800
(SUPERIOR TUBE CO., HEAT # NH256A)

A. CHEMISTRY

C	Mn	S	Si	Ni	Cr	Co	Ti	Ca	Fe
0.5	.65	.012	.31	31.86	20.10	.24	.42	.21	Balance

B. TENSILE PROPERTIES

<u>Treatment</u>	<u>Temp. °F</u>	<u>0.2% Y. Strength, PSI</u>	<u>Ult. Strength PSI</u>	<u>% Uniform Elong. in 2 in.</u>
CW, As Received	70	79,400	96,300	26
CW, As Received	70	79,000	96,000	27
CW, As Received	800	66,450	84,150	15
CW, As Received	1000	63,000	80,700	19
CW, As Received	1000	66,300	80,950	-
CW, As Received	1200	54,150	69,150	9.5
Swage to .453, 5 hrs. @ 1650°F Swage to .450	70	69,050	75,200	-
Swage to .460, 15 min. @ 1850°F, A/Q Swage to .450	70	62,700	91,550	30.4
1 hr. @ 1550°F	70	57,400	90,850	37.0
15 min. @ 1800°F	70	55,600	89,750	33.7
15 min. @ 1950°F	70	28,700	81,400	43.1
Annealed, As Received	70	30,800	80,500	49.0
Annealed, As Received	70	30,500	80,900	50.0

* No distortion during air quench

TABLE III-4 (CONT'D)

C. BURST PROPERTIES

<u>Treatment</u>	<u>Temp. °F</u>	<u>Burst Pressure PSI</u>	<u>% Increase in O.D.</u>
CW, As Received	1000	3700	1.8
3 Days @ 1250°F	1000	3300	3.6
7 Days @ 1250°F	1000	3400	4.5
12 hr. @ 1350°F	1000	3200	3.3
12 hr. @ 1450°F	1000	3200	3.3
48 hrs. @ 1450°F	1000	2900	2.2
1 hr. @ 1550°F	1000	3200	6.9
5 hr. @ 1550°F	1000	3150	5.1
1 hr. @ 1650°F	1000	3200	5.8
5 hr. @ 1650°F	1000	3000	8.9
15 min. @ 1950°F	1000	2700	17.7
Swage .493 to .450 O.D.	1000	3600	3.1
Swage .493 to .450 O.D.	1000	3500	2.4
Swage .493 to .460	1000	3400	6.0
15 min. @ 1850°F			
Swage .460 to .450			
Swage .493 to .453	1000	3200	5.2
5 hrs. @ 1650°F			
Swage to .450			

TABLE III-5

MECHANICAL PROPERTIES OF 16 Cr-20 Ni STAINLESS STEEL
(CARPENTER STEEL COMPANY, HEAT #V 90548)

A. CHEMISTRY

C	Mn	Si	P	S	Cr	Ni	Mo	N	Co
.009	.07	.06	.004	.002	16.55	20.55	.04	.009	.02

B. TENSILE PROPERTIES

<u>Treatment</u>	<u>Temp. °F</u>	<u>0.2% Y. Strength, PSI</u>	<u>Ult. Strength PSI</u>	<u>% Uniform Elong. in 2 in.</u>
CW, As Received	70	70,000	85,200	24.0
CW, As Received	70	73,500	84,800	28.0
CW, As Received	70	76,600	85,500	24.0
CW, As Received	800	62,350	65,150	1.5
CW, As Received	800	61,050	65,850	1.6
CW, As Received	1000	57,500	60,300	1.7
CW, As Received	1000	57,450	60,400	1.8
CW, As Received	1200	44,050	47,850	3.7
CW, As Received	1200	43,800	48,150	3.0
5 hrs. @ 1350°F	70	57,350	79,200	26.1
Swage .493 to .460	70	44,500	66,350	28.5
6 hrs. @ 1950°F max.				
Swage .460 to .450				
Annealed, As Received	70	31,400	64,300	46.0
Annealed, As Received	70	32,400	64,300	43.0

TABLE III-5 (CONT'D)

C. BURST PROPERTIES

<u>Treatment</u>	<u>Temp. °F</u>	<u>Burst Pressure PSI</u>	<u>% Increase in O.D.</u>
CW, As Received	70	4100	1.1
CW, As Received	800	3700	0.4
CW, As Received	800	3400	0.4
CW, As Received	1000	3200	0.1
CW, As Received	1000	2900	0.4
CW, As Received	1000	2900	0.7
15 min. @ 1950°F	70	2600	16.7
15 min. @ 1950°F	800	1800	11.1
15 min. @ 1950°F	1000	1700	10.0
15 min. @ 1950°F	1000	1900	12.2
5 min. @ 1850°F	800	2000	16.7
5 min. @ 1850°F	800	2100	14.4
5 min. @ 1700°F	800	2100	13.3
8 min. @ 1650°F	800	2200	12.2
5 min. @ 1600°F	800	2500	5.1
1 hr. @ 1450°F	1000	2450	2.2
5 hr. @ 1450°F	1000	2100	10.5
12 hr. @ 1450°F	1000	1900	11.5
1 hr. @ 1350°F	1000	2500	3.2
5 hr. @ 1350°F	1000	2200	9.1
12 hr. @ 1350°F	1000	1900	11.3
48 hr. @ 1350°F	1000	2000	16.0
3 days @ 1250°F	1000	2300	1.8

TABLE III-5 (CONT'D)

<u>Treatment</u>	<u>Temp. °F</u>	<u>Burst Pressure PSI</u>	<u>% Increase in O.D.</u>
3 days @ 1250°F	1000	2400	2.2
7 days @ 1250°F	1000	2300	1.6
7 days @ 1250°F	1000	2300	1.3
11 days @ 1250°F	1000	2200	2.2
11 days @ 1250°F	1000	2200	2.0
Swage .393 to .450	800	2500	0.0
Swage .493 to .450	800	2900	0.0
Swage .493 to .460, 6 hrs. @ 1950°F max., Swage .460 to .450	1000	2100	7.8

TABLE III-6

METALLURGICAL CONDITION OF CLADDING AS A
FUNCTION HEAT TREATMENT

64-III

MATERIAL	GRAIN BOUNDARY PRECIPITATION				TWINNING PLANE PRECIPITATION				COLD WORKED GRAINS EVIDENT	LARGE GRAIN SIZE	SPECIMEN NO.
	NONE	GLOBULAR	DISCONTINUOUS	CONTINUOUS	NONE	GLOBULAR	DISCONTINUOUS	CONTINUOUS			
Incoloy 800 CW - As Received		X	X	Little					YES		8884
* Incoloy 800 CW - 15 min @ 1800°F		X	X		Isolated						8885
Incoloy 800 - CW - 15 min @ 1950°F	Little			Little					YES		8883
Incoloy 800 CW - 5 hr. @ 1650°F		X		X		X		X			8881
Incoloy 800 CW - 5 hr. @ 1550°F				X		X		X			8882
Incoloy 800 CW - 7 day @ 1250°F				X				X			8904
Incoloy 800 CW - 7 day @ 1250°F				Heavy		X		X			8905
Incoloy 800 CW - 7 day @ 1250°F											8913
Incoloy 800 Annealed - As Received		X		Little							8875
Incoloy 800 Annealed - Swage to .460/ 1850°F, 15 min./Swage to .450		X		X		X					8921
16-20 CW - As Received	X				X						8810
16-20 CW - 5 hrs. @ 1350°F		Large	X		X				NO		8923
16-20 Annealed - As Received	X				X						8809
* 16-20 Annealed - Swage to .460/ 1950°F, 15 min./Swage to .450	X								Double		8920

*Reference Heat Treatment

X - Indicates Appropriate Description

Vibratory Compacted and Swaged Rods

Incoloy - Swage to 0.460 inch diameter, anneal at 1800°F, water spray quench from annealing temperature, and swage to final diameter.

16-20 - Swage to 0.460 inch diameter, anneal at 1950°F, and swage to final diameter.

One reason for specifying an 1800°F anneal (mill anneal) instead of a 2100°F anneal (solution anneal) for Incoloy was to obtain a smaller grain size. There is recent evidence that a smaller grain size results in greatly improved strain fatigue characteristics.

5.3 FUEL LOADING PROCEDURE DEVELOPMENT

Pelleted Fuel Rods

Early attempts at obtaining a close or interference fit between clad and pellet were unsuccessful. It was hoped that this could be accomplished by inserting cold pellets into a tube heated to about 900°F. A successful technique was developed for loading pellets at room temperature, with a maximum diametral clearance of 0.001 inch. This involved the use of a vibratory technique using a maximum shaker acceleration of 8 g's.

During the development period, a total of five depleted UO₂ prototype rods were prepared. Pellets were ground to a maximum 0.001 inch diametral clearance with the clad I.D. and were hand loaded into the clad. Unacceptable gaps in excess of 0.005 inch between pellets were found by X-ray. Next, pellets with the same diametral clearance were vibrated into the vertical rod with 40 g maximum acceleration. A cracked pellet was found in this rod by X-ray which resulted in an unacceptably large axial gap. A third rod was prepared using the same process but 8 g's maximum shaker acceleration. No cracked pellets or gaps between pellets in excess of 0.005 inches were found in the X-rays which were taken every 3 inches

along the rod length. One gap of .03 inches was found between the bottom end plug and the first pellet. Production lower end plugs will be machined to zero clearance with the clad, eliminating the problem.

Vibratory Compacted and Swaged Rods

During the development period, a total of eight prototype rods were loaded with depleted arc fused powder, vibratory compacted and swaged. During swaging, a fuel rod is reduced from 0.493 to 0.450 inches O.D. in 0.010 inch steps. It was found necessary to center and support a rod on each side of the die to maintain straightness tolerances. Completed rods are straight within 0.010 inch over their total length when they have supported and centered within a sleeve allowing an 0.015 maximum diametral clearance. Final diameters run within 0.449 and 0.451 O.D., which is within the allowed tolerance of 0.4485 to 0.4515 O.D. No sign of clad thinning over the fuel has been detected. Clad over the solid end plugs has been found to be reduced to 50% of the original wall thickness. Production rods, therefore, will have new end plugs welded on, after swaging, to eliminate the thinned region in the clad.

Burst tests of two prototype fuel rod tubing, after removal of the fuel, showed that both the Incoloy 800 and 16-20 cladding has insufficient ductility after cold swaging from 0.493 to 0.450 inches O.D. Further tests showed that sufficient cladding ductility can be obtained by incorporating an intermediate annealing step. The final heat treatment procedures that were adopted are given in Section 5.2 above.

Pressure Bonded Fuel Rods

The feasibility of using high-temperature, gas-pressure bonding as a technique for fabricating UO_2 fuel elements for tests in a supercritical environment was evaluated. A total of four fuel rods were prepared by Westinghouse and shipped to Battelle Memorial Institute (BMI) for pressure bonding. Two of these fuel rods were prepared with a 70%, -100 to +200 mesh fused and 30% ceramic grade UO_2 mixture, vibratory compacted, and swaged. Two additional rods were prepared by vibratory compacting and swaging arc-fused UO_2 powder to 90-91% of theoretical density. Details of the rods are given in the following tabulation:

<u>Rod No.</u>	<u>4 INC-DUDC</u>	<u>08-1-DBV</u>	<u>05-1-DBV</u>	<u>07-1-DBV</u>
Total Rod Length, in.	40.725	26.250	15.430	13.314
Total End Plug Length, in.	1.950	1.820	2.60	2.250
Total Fuel Length, in.	38.775	24.430	12.830	11.064
Average Rod Diameter, in.	0.4502	0.4506	0.4681	0.4672
Type of UO ₂	100% fused	100% fused	70% fused 30% ceramic	70% fused 30% ceramic
Weight of UO ₂ , gm	916.1	579.05	250.4	215.9
% of Theoretical Density	90.97	91.1	69.34	69.55
Cladding Material	Incoloy	16-20 SS	16-20 SS	16-20 SS
Approx. Clad Thickness, in.	0.010	0.010	0.010	0.010

All four rods were pressure checked in 200 psi helium and found to be leak-tight. A dimensional survey was run on each rod to determine variations in rod diameter and amount of camber and provide a comparison with corresponding data to be taken after pressure bonding. This information is included in Tables III-7, 8, 9 and 10 where both prebonding and post-bonding data are listed. Only rod 05-1-DBV was found to show an excessive initial variation in diameter (0.4653 to 0.4716 in.).

Camber was found to be the greatest on the longest rod of this group, (Rod No. 4 INC-DUDC), in which case a camber of 0.0452 in. was recorded at a point 22 in. from the numbered end.

All rods were again pressure checked in helium and found to be leak-tight, thus indicating that the system pressure was effective throughout the bonding cycle. Radiographs were taken on all rods, and a core-clad void was noted only in Rod 07-1-DBV, which corresponded to the area which buckled during pressure bonding. Since the rods were leak-tight, both before and after bonding, this void is believed due to a gas or moisture content of the oxide powder at this location. Its contribution to the buckling observed cannot be determined at this time.

TABLE III-7

DIMENSIONAL CHANGES (ROD 4 INC-DUDC)

Position, in. from Numbered End	Diameter, In.		Average Decrease Diam, In.(b)		Average Bonding Temp of (c)	Remarks
	Before Bonding 0°	90°	After Bonding 0°	90°		
1	.4495	.4495	.4456	.4455	.0035	End plug area
2	.4499	.4497	.4465	.4467	.0032	
3	.4501	.4499	.4475	.4473	.0026	TC out
4	.4500	.4497	.4475	.4474	.0024	
5	.4500	.4498	.4475	.4475	.0024	
6	.4501	.4498	.4470	.4472	.0029	2020
7	.4500	.4497	.4472	.4475	.0025	
8	.4499	.4497	.4474	.4475	.0023	
9	.4499	.4497	.4471	.4473	.0026	2000
10	.4499	.4496	.4476	.4475	.0022	
11	.4499	.4497	.4478	.4476	.0021	
12	.4501	.4499	.4477	.4475	.0024	2030
13	.4502	.4499	.4475	.4478	.0024	
14	.4499	.4499	.4476	.4474	.0024	
15	.4497	.4492	.4476	.4476	.0024	2040
16	.4501	.4499	.4478	.4480	.0026	
17	.4497	.4498	.4475	.4475	.0027	
18	.4499	.4495	.4475	.4478	.0023	1980
19	.4499	.4495	.4475	.4474	.0023	
20	.4499	.4495	.4472	.4471	.0025	
21	.4498	.4496	.4476	.4475	.0021	1950
22	.4499	.4495	.4475	.4475	.0022	
23	.4501	.4497	.4475	.4478	.0023	
24	.4502	.4497	.4478	.4478	.0022	1950
25	.4500	.4496	.4479	.4479	.0019	
26	.4503	.4496	.4478	.4479	.0021	
27	.4500	.4498	.4474	.4475	.0025	2020
28	.4500	.4497	.4478	.4477	.0021	
29	.4501	.4496	.4475	.4475	.0024	
30	.4499	.4497	.4477	.4477	.0021	1860
31	.4499	.4496	.4475	.4475	.0022	
32	.4497	.4495	.4480	.4479	.0017	
33	.4498	.4495	.4479	.4480	.0017	1575
34	.4498	.4495	.4480	.4480	.0017	
35	.4498	.4494	.4480	.4478	.0017	
36	.4496	.4495	.4473	.4477	.0020	1350
37	.4495	.4494	.4470	.4470	.0025	
38	.4499	.4464	.4458	.4448	.0029	Indent area
39						1050

*Footnotes appear on following page

TABLE III-7 (CONT'D)

Footnotes to

DIMENSIONAL CHANGES (ROD 4 INC-DUDC)

- (a) Specimen jigged in 304 SS rod assembly (.5 in. diam) and bonded for 3 hours at 10,000 psi and 2000F.
- (b) ΔD of 0.002 = 1% decrease in area/1% increase in ϵ .
 ΔD of 0.003 = 1.5% decrease in area/1.5% increase in ϵ .
- (c) Approximate average for 3 hr. run: thermocouples at given locations outside can assembly.

$$\Delta L = 40.725 \text{ in.} - 40.3125 \text{ in.} = 0.4125 \text{ in. decrease. (approximately 1\% (1\% increase in } \epsilon \text{))}$$

CAMBER MEASUREMENTS:

<u>Distance from Numbered End. in.</u>	<u>Before Bonding, in.</u>	<u>After Bonding, in.</u> (1)
6	0.0185	0.0485
14.5	0.0400	0.0330
22	0.0452	0.0409

- (1) Free path for rod in assembly would permit up to 0.050 in camber - this can be reduced with a redesigned assembly.

TABLE III- 8

DIMENSIONAL CHANGES (ROD 08-1-DBV) (a)

Position, in. from Numbered End	Diameter, in.				Average Decrease in Diam, in. (b)	Average Bonding Temp, °F (c)	Remarks
	Before Bonding		After Bonding				
	0°	90°	0°	90°			
1	.4513	.4507	.4495	.4490	.0018	--	End plug area, TC out.
2	.4516	.4511	.4485	.4475	.0034		
3	.4520	.4514	.4485	.4485	.0032	2205	
4	.4516	.4514	.4475	.4478	.0036		
5	.4519	.4514	.4470	.4478	.0042		
6	.4522	.4515	.4485	.4480	.0036	2180	
7	.4519	.4517	.4485	.4480	.0036		
8	.4522	.4517	.4487	.4485	.0034		
9	.4517	.4510	.4475	.4475	.0038	2205	
10	.4514	.4515	.4474	.4473	.0041		
11	.4517	.4515	.4470	.4470	.0046		
12	.4517	.4516	.4478	.4475	.0040	2215	
13	.4516	.4512	.4480	.4480	.0034		
14	.4519	.4519	.4475	.4475	.0042		
15	.4513	.4514	.4480	.4475	.0036	2210	
16	.4515	.4514	.4479	.4480	.0035		
17	.4514	.4514	.4482	.4478	.0034		
18	.4515	.4515	.4483	.4475	.0036	2180	
19	.4524	.4513	.4490	.4475	.0036		
20	.4523	.4514	.4492	.4483	.0031		
21	.4516	.4515	.4482	.4484	.0032	2185	
22	.4516	.4513	.4485	.4478	.0033		
23	.4515	.4514	.4480	.4481	.0034		
24	.4513	.4515	.4482	.4478	.0034	2210	
25	.4503	.4501	.4471	.4465	.0035		
26	.4486	.4484	.4482	.4480	.0004	2190	End plug area

DIMENSIONAL CHANGES (ROD 08-1-DBV)

(a) Specimen jugged in Al_2O_3 tube and placed in can with 30h SS rods for bonding 3 hrs. at 2200F and 10,000 psi.

(b) ΔD of 0.003 = 1.3% decrease in area/1.3% increase in ρ .
 ΔD of 0.004 = 1.78% decrease in area/1.78% increase in ρ .

(c) Approximate average for 3 hr. run at location indicated.

$$\Delta L = 27.193 - 26.828 = 0.365 = 1.3\% \text{ decrease}/1.3\% \text{ increase in } \rho.$$

CAMBER MEASUREMENTS

Distance from Numbered End in.	Before Bonding in.	After Bonding in.
7	0.0055	0.027
13	0.0052	0.0556
19	0.0105	0.0287

TABLE III-9

DIMENSIONAL CHANGES (ROD 051-DBV)

Position in. from Numbered End	Diameter, in.				Average Decrease in Diam, in.	Average B Bonding Temp, °F	Remarks
	Before Bonding		After Bonding				
	0°	90°	0°	90°			
1	.4676	.4700	.4760	.4742	+ .007	--	End plug, TC out
2	.4653	.4716	.4242	.4241	.0443		
3	.4657	.4702	.4321	.4305	.0366	2205	
4	.4673	.4692	.4355	.4361	.0325		
5	.4676	.4685	.4300	.4288	.0387		
6	.4638	.4711	.4192	.4212	.0472	2180	
7	.4654	.4693	.4184	.4188	.0487		
8	.4665	.4697	.4392	.4405	.0282		
9	.4677	.4703	.4355	.4465	.0280	2205	
10	.4683	.4698	.4370	.4255	.0378		
11	.4688	.4694	.4248	.4382	.0376		
12	.4692	.4692	.4420	.4451	.0257	2215	
13	.4685	.4686	.4375	.4365	.0315		
14	.4678	.4682	.4700	.4694	+ .0022		End Plug
15	.4650	.4645	--	--		2210	

(a) Pressure bonded 3 hrs. at 2200F and 10,000 psi

CAMBER MEASUREMENTS

Distance from Numbered End, in.	Before Bonding in.	After Bonding in.
4	--	0.1061
8	0.0064	0.0805
12	--	0.0320

$$\Delta L = 15,433 - 14,562 = 0.871 = 5.6\%$$

TABLE III-10

DIMENSIONAL CHANGES (ROD 071-DBV)

Position, in. from Numbered End	Diameter, in.				Average Decrease in Diam, in.	Average Bonding Temp, °F	Remarks
	Before Bonding		After Bonding				
	0°	90°	0°	90°			
1	.4702	.4700	0.4720	0.4725	+ .0021	1780	
2	.4693	.4697	0.4355	0.4340	- .0347		
3	.4690	.4694	0.4260	0.4278	- .0423	--	TC out
4	.4698	.4705	0.4152	.4198	- .0526		
5	.4690	.4685	.4795	.4798	+ .0109		Bulged area
6	.4688	.4688	.4322	.4358	- .0348	2020	
7	.4693	.4685	.4265	.4260	- .0226		
8	.4689	.4684	.4237	.4365	- .0385		
9	.4686	.4687	.4450	.4349	- .0287	2000	
10	.4692	.4684	.4442	.4365	- .0284		
11	.4685	.4686	.4425	.4315	- .0315		
12	.4694	.4690	.4648	.4646	- .0045	2030	

Pressure bonded 3 hr at 2000F and 10,000 psi

CAMBER MEASUREMENTS

0.0276 over length before bonding

After bonding:

numbered end	0.2208
center	0.0160
opposite end	0.1003

A dimensional study was performed on each rod to compare with the initial data. Both sets of data are compared in Tables III-7, 8, 9, and 10, where diameter changes at each point, average bonding temperatures, and changes in camber are recorded. The fused oxide rods, (Tables III-7 and III-8) showed an average density increase of 2 to 2.5 percent and 2.6 to 3.1 percent at the 2000 and 2200F bonding temperatures respectively. Based on the initial density of approximately 91 percent of theoretical, the final densities of the fused rods are 93 and 94 percent of theoretical. It is interesting to note that in Rod 4 INCDUDC, which extended out of the autoclave furnace, a diameter shrinkage corresponding to a 1% decrease in area was noted at the cold end (approximately 1200°F). This suggests that densification may be attained at temperatures well below the nominal bonding temperatures of these experiments. Dimensionally, the fused oxide rods appear excellent as diameter variations are held with $\pm .001$ in. excluding the end plug areas.

The camber in the fused oxide rods was retained within 0.056 in. This camber could be greatly reduced with a precision clamped plate device for bonding. Considering the free path permitted in the current tests, the rod cambers have been controlled within the intended limits.

The fuel rods containing mixed fused and ceramic oxides do not lend themselves as readily to comparison because of the irregularities observed. With both rods of this type, accurate densities cannot be determined, although estimates have placed both final densities above 90% of theoretical. It is believed that controlled deformation with such rods would require a more uniform distribution of the two oxides in the initial packing and more rigid containment and support of the cladding surfaces during bonding. Since considerably more deformation occurs in these rods as compared to fused oxide rods, fixtures of a completely different design should be employed during bonding to approach a $\pm .001$ tolerance on rod diameters.

The brief experiments described above show that pressure bonding in its present state of development cannot be used to fabricate satisfactory thin-walled clad supercritical fuel elements from mixtures of fused and ceramic oxides. The major problem areas are rough surfaces and poor dimensional control.

With fuel rods containing vibratory compacted and swaged-fused UO_2 , pressure bonding can be used to increase the fuel density from 91% to 93-94% of theoretical. Since a minimum deformation is involved, excellent surface finish and dimensional control can be obtained. Since these rods were subjected to temperatures and pressures which greatly exceed those in our supercritical environment, added confidence in our vibratory compacted and swaged fabrication process was obtained.

Unfortunately, the economic incentive of using pressure bonding to increase fuel density above 91% is small, thus no further work on pressure-bonded fuel elements is planned.

5.4 WELDING DEVELOPMENT

Incoloy 800 End Plug Welding

The initial heats of as-received Incoloy 800 Vipac and pellet tubes exhibited cracking during end plug welding. Subsequent metallographic examination of tube cross sections revealed severe grain boundary precipitation. Concentrations of these precipitates are believed responsible for weld cracking. The material was returned to the vendor for reprocessing by solution annealing. Solution annealing was accomplished by holding the tubing at $2150^{\circ}F$. for approximately an hour and quenching to room temperature. Although the quantity of precipitates were reduced, 1 localized concentrations were still observed at the grain boundaries.

Attempts to weld the reprocessed tubing by standard welding procedures resulted in crater cracking at the point where the arc was extinguished. Modifying the welding process, by tapering the current down to six amps prior to extinguishing the arc, eliminated the crater cracking problem. Subsequent burst test of end plug welds by the modified process resulted in failure of the clad away from the weld.

New tubing was procured from second heat of material. The new heat of material was annealed at 1800°F. and quenched. Metallorgraphic examination revealed no serious grain boundary precipitation. No welding problems were encountered with the second heat of material. Final welding parameters are given in Section 5.5 below.

16 Cr - 20 Ni End Plug Welding

16 Cr - 20 Ni stainless steel is extremely weldable. There were no welding difficulties encountered at any time. Welding parameters are given in Section 5.5 below.

5.5 FINAL PROCESS PRECEDURES

Process Procedures for Assembly of Pelleted Fuel Rods

The following procedures cover the fabrication and assembly of pelleted fuel rods. The procedures start after the components have been accepted by Receiving Inspection.

- *1. Clean tube: For the inside diameter, use pads dampened with acetone and ethyl alcohol in that order. Blow pads through the bore using dry ditrogen gas. Wipe the outside surface of the tube with clean cloths dampened with acetone and ethyl alcohol, in that order.

*For all cleaning and handling operations wear protective gloves as necessary to keep parts clean.

2. Clean lower end plug: Again, use acetone and ethyl alcohol solvents. Wipe carefully with clean cloths dampened with respective solvent. Hot air dry to make certain all solvent has evaporated.
3. Clean one end of the tube on the I.D. with ethyl alcohol and Q-tips. This is the end which will take the end plug. Hot air dry to evaporate all solvent.
4. Press in the lower end plug and check fit-up.
5. Weld end closure:

For both 16-20 and Incoloy 800 materials: Weld at 18 to 20 amps with a fixed heat electrode having 0.020 to 0.021 inch arc gap. The voltage at this setting will range between 15.0 to 17.5 arc volts. Set speed of rotation of the work piece at 15 to 16 RPM. Set the welding time for 5.5 seconds and taper time for 1.5 seconds. Taper from welding current down to 8 to 10 amps. Use helium as the inert gas.
6. Dye-check end closure before further processing. With a vibra-tool inscribe fuel rod number on taper on lower end plug.
7. Machine tube to an inside length of 39.5 inches. Slightly flare the tube end to facilitate pellet loading. Accurately measure the inside tube length. Use a previously measured gage piece to fit inside the tube and depth micrometers. Record this dimension.
8. Dry UO_2 pellets (0.4280 inch diameter) at 90°C for one to two hours before loading them into the closed end tube.
9. Obtain the following data before loading the UO_2 pellets and record on Fuel Rod Record Card for pelleted rods:
 - a. Length of pellet column.
 - b. Number of pellets needed. Record individual pellet numbers with weight and length of each.

- c. Weight of pellets.
 - d. Inside length of tube (with lower end plug welded on).
 - e. Weight of empty tube with lower end plug.
10. Attach the closed end tube to a vibratory exciter shaker table. Clamp onto the end plug portion and not the tube wall.
 11. Wear non-porous gloves while handling pellets during loading.
 12. Energize vibration exciter to operate at 600 to 700 cycles per second. The frequency and acceleration level may be varied to assist in loading. Use minimum G's.
 13. Load UO_2 pellets into the tube. Insert pellets one at a time and adjacent to one another.
 14. Obtain the following data after loading the UO_2 pellets and record on Fuel Rod Record Card:
 - a. Pellet column length.
 - b. UO_2 pellet weight inside tube.
 15. Machine the tube to length according to drawing 881D766.
 16. Machine the insert portion of the upper end plug to suit the distance from the tube end to the UO_2 pellet column and counterbore for the gas plug. Press the gas plug into the counterbore.
 17. Clean both the upper end plug and gas plug.
 18. Clean the tube end with ethyl alcohol and Q-tips. Hot air dry to evaporate all alcohol. Remove all dirt from tube end that will contact end plug.
 19. Press in upper end plug and check fit-up.
 20. Weld upper end closure: See Section 5 of this procedure. Do not weld vent hole yet.

21. Vacuum heat treat the fuel rod at 750°F for two hours. Without opening the cooled retort (and fuel rod) to air atmosphere, transfer the fuel rod into a vacuum tight weld box.
22. Evacuate the weld box and back-fill with helium to atmospheric pressure.
23. TIG fusion weld (at approximately 25 amps) to seal the vent hole in the upper end plug. Obtain a penetration of at least 0.015 inch. Remove fuel rod from the weld box.
24. Dye-check vent hole seal weld and second end closure.
25. With a vibra-tool inscribe fuel rod number on upper end plug. See drawing 881D766.
26. Machine hole in lower end plug for wire wrap; index from upper end plug.
27. Clean fuel rod.
28. X-ray full length of fuel rod. Check fuel length and end closures.
29. Clean fuel rod.
30. Pressure test fuel rod at 3000 psi and 700°F for 30 minutes at pressure and temperature.
31. Wire wrap the fuel rod. Adjust the wire wrap machine for either the clockwise or counter clockwise wrapping direction.
 - a. Obtain a piece of wire of sufficient length.
 - b. Bend the wire 90° and insert it in the hole in the lower end plug. Trim off excess wire protruding through the hole.
 - c. Fusion TIG weld in place.
 - d. Set up fuel rod and wire wrap on wire wrap machine.
 - e. Wire wrap fuel rod on a 10 inch pitch.
 - f. Bend wire at 90° to insert through the hole in the upper end plug. Trim off excess wire protruding through the hole.
 - g. Fusion TIG weld in place.

32. Clean fuel rod.
33. Final inspect fuel rod per drawing 881D766.
34. Clean and bag fuel rod to await further assembly operations.

Process Procedures for Assembly of Vibratory Compacted and Swaged Fuel Rods

The following procedures cover the fabrication and assembly of vibratory compacted fuel rods. The procedures start after the components have been accepted by Receiving Inspection.

- *1. Clean tube: For the inside diameter, use pads dampened with acetone and ethyl alcohol, in that order. Blow pads through the bore using dry nitrogen gas. Wipe the outside surface of the tube with clean cloths dampened with acetone and ethyl alcohol, in that order.
2. Clean temporary lower end plug: Again, use acetone and ethyl alcohol solvents. Wipe carefully with clean cloths dampened with respective solvent. Hot air dry to make certain all solvent has evaporated.
3. Clean one end of the tube on the I.D. with ethyl alcohol and Q-tips. This is the end which will take the end plug. Hot air dry to make certain solvent has evaporated.
4. Press in the temporary lower end plug and check fit-up. From this operation on, keep tube or rod protected in polyethylene wrapping, preferably 1-1/4" sleeving.

5. Weld end closure:

For both 16-20 and Incoloy 800 materials; weld with a fixed head electrode at 18 to 20 amps, 0.020 inch to 0.021 inch arc gap, and a rotation speed of 15 to 16 RPM. Voltages at this setting should run from 13.5 to 17.5 arc volts. Weld time 5.5 seconds then taper for 1.5 seconds from welding current down to 8 to 10 amps. The electrode should be 1/16" diameter 2% thoriated tungsten tapered at the ends with a 1/32" flat on the end. Use 100% helium

* For all cleaning and handling operations wear protective gloves as necessary to keep parts clean.

for inert gas. Position the electrode 1/32" on the down-hill side of the weld. The electrode flat will be over the end plug with the outside edge of the flat directly over the weld joint.

6. Dye-check end closure before further processing.
7. Machine tube to 35.75 inches inside length.
8. Dry the fused UO_2 particles at 100°C for two hours before preparing the fused UO_2 charge weight.
9. Obtain the data requested on the attached Fuel Rod Record Card for Vibratory Compacted Rods. This will cover information required on the fuel rod before loading.
10. Weigh out and hand-blend the mixture of fused UO_2 . The mixture will consist of the following:

55% of;	-16	+ 20	particle size
25% of;	-60	+ 100	particle size
20% of;	-200		particle size
11. Attach the closed end tube to a vibratory exciter shaker table. Clamp onto the end plug portion and not the tube wall.
12. Wear rubber gloves while loading the fused UO_2 .
13. Feed the fused UO_2 blend using a Syntron vibrator through a hopper and connected to the top of the tube with Tygon tubing. During loading operate the electrodynamic vibration exciter at 400 cycles per second.
14. After loading, shut off the vibration exciter and disconnect the Syntron feeder from the tube.
15. Vibratory compact by energizing the vibration exciter to automatically sweep a range of frequencies from 200 through 750 cycles per second. During the compacting period, the UO_2 column inside the tube may be held down with about 10 pounds force. This will be done manually using a tamping rod. Vibratory compacting will continue until a theoretical density of 80 to 85% is obtained.

16. Remove the rod from the shaker table. Obtain data on vibratory compacted fuel rod (length of column, weight of UO_2 and % T.D.). Record on Fuel Rod Record Card.
17. Vacuum heat treat at 90° to 100°C for 1 to 2 hours.
18. Machine tube to length: The UO_2 column length at this point has been fixed by the charge weight and density. Do not remove any fuel. Insert a dummy plug to rest on top of the fuel and to keep it in place during machining of the tube. The dummy plug will have a known length, diameter, and weight. The tube will be machined to a certain length by measuring, with depth micrometers, the distance from the top of the insert plug to the end of the tube. This distance will be made to suit the insert portion of the temporary upper end plug so that after it is inserted into the tube, there will be a 0.007 to 0.010 inch gap between the top of the dummy insert plug and the end plug.
19. Thoroughly clean the inside of the tube which will be in contact with the end plug.
20. Clean the tube end with ethyl alcohol and Q-tips. Hot air dry to evaporate all alcohol.
21. Clean the temporary upper end plug using the same procedure as Section 2 of this procedure.
22. Press in temporary upper end plug and check fit-up.
23. Weld end closure: See Section 5 of this procedure.
24. TIG weld to seal vent hole in temporary upper end plug. Obtain a minimum of 0.020 inch penetration.
25. Dye-check vent hole seal weld and second end closure.

26. Clean fuel rod and identify with fuel rod number on temporary lower and upper end plugs. Use a Vibratory Tool to inscribe number on a part of the end plug that won't be affected during swaging.
27. Swage fuel rod from 0.494 inch diameter to 0.456/0.460 inch diameter. Reverse tubing direction for each swaging pass. Record swaging data: die size, tube diameter, end plug diameter, length, and any unusual conditions.
28. The fuel rod at this point must be heat treated before final swaging to 0.450 inch diameter. Drill a through-hole in the bottom end plug; enough to just break through into the UO_2 fuel. The diameter of the hole should be about 0.052 inch. The purpose of the hole is to allow release of gas pressure during the heat treatment which follows.
29. Fixture the fuel rod to prevent drastic dimensional changes during heat treatment.
30. Heat treat the fuel rod.
 - a. For 16-20 clad vibratory compacted fuel rods: Insert fixtured rod into a retort at room temperature. Purge with argon to remove the air atmosphere and then introduce hydrogen. Light-off hydrogen. Insert the retort into a furnace which has been idling at 1300°F. Set the furnace controls up to provide a work-piece temperature of 1950°F. Check temperature inside retort (with a thermocouple) and note and record when temperature is 1950°F. Hold for 15 minutes at temperature then set furnace controls back to 1300°F. Furnace-cool to 1300°F. Purge with argon to extinguish hydrogen and seal off retort with argon inside retort. Remove retort from furnace and air-cool. Open retort and remove fixtured fuel rod. Keep a log on each fuel rod heat treated.
 - b. For Incoloy 800 vibratory compacted fuel rods: (Later, if required.)

31. TIG fusion weld to seal the vent hole in the lower end plug and finish swaging to 0.450 ± 0.0015 inch diameter.
32. Measure O.D.
33. Remove temporary upper end plug and the dummy plug. Save all UO_2 fuel removed.
34. Machine tube end square.
35. Machine permanent upper end plug to suit distance from top of tube to the top of UO_2 column. Machine recess in upper end plug for gas plug. Clean upper end plug.
36. Press in cleaned gas plug in recess in upper end plug.
37. Clean the tube end with ethyl alcohol and Q-tips. Hot air dry to evaporate all alcohol.
38. Press in upper end plug and check fit-up.
39. Weld end closure: See Section 5 of this procedure.
40. Do not weld vent hole yet. Keep fuel rod in polyethylene sleeving to prevent damage at this end.
41. Remove temporary lower end plug. Save all UO_2 fuel removed.
42. Measure distance from end of upper end plug to the tube cut-off point at the lower end.
43. Machine a permanent lower end plug to suit over-all fuel rod length on drawing 882D143. It may be necessary to sacrifice fuel length for fuel rod over-all length which must be held. If any fuel must be removed, save it.
44. Clean lower end plug and tube: see Sections 2 and 37 of this procedure.

45. Press in permanent lower end plug. Check fit-up.
46. Weld end closure: see Section 5 of this document.
47. Dye check end closure weld.
48. Weight all UO_2 fuel removed and record on fuel rod record form. Record weight of fuel inside tube.
49. Heat in vacuum to 750°F for two hours. Without allowing the fuel rod to be exposed to air atmosphere, transfer the rod into a vacuum weld box.
50. Evacuate the weld chamber and the fuel rod through the vent hole in the upper end plug.
51. Back fill to atmospheric pressure with helium gas.
52. TIG fusion weld to seal the vent hole in the upper end plug. Remove the fuel rod from the weld box.
53. Dye check end closure weld and vent hole weld in the upper end plug.
54. X-ray end closures and fuel length of fuel rod.
55. Helium leak check fuel rod.
56. Pressure test fuel rod at 4000 psia and room temperature for five minutes and dimensionally inspect.
57. Gamma scan.
58. Wire wrap the fuel rod. Adjust the wire wrap machine for either the clockwise or counter clockwise wrapping direction, whichever is applicable.
 - a. Obtain a piece of wire of sufficient length.
 - b. Bend the wire 90° and insert it in the hole in the lower end plug. Trim off excess wire protruding through the hole.

- c. Fusion TIG weld in place.
 - d. Set up fuel rod and wire wrap on wire wrap machine.
 - e. Wire wrap fuel rod on a 10 inch pitch.
 - f. Bend wire 90° to insert through the hole in the upper end plug.
Trim off excess wire.
 - g. Fusion TIG weld in place.
59. Clean fuel rod.
60. Final inspect fuel rod per drawing 882D143.
61. Clean and bag fuel rod to wait further assembly operations.

REFERENCES

1. Keyfitz, I. M., Gorman, P. F., et al, (J&M), "1000 MWe Supercritical Pressure Nuclear Power Plant Design Study," WCAP-2240, January 1964.
2. Wright, J. H., Patterson, J. F., "Status and Application of Supercritical - Water Reactor Coolant," American Power Conference, Chicago, Ill., April 26-28, 1966.
3. Aase, D. T., et al, "Economic Evaluation of a 300 MWe Fast Supercritical Pressure Power Reactor," HW-78935, December 9, 1963.
4. Edlund, M. C., MacMillian, J. H., Schluderberg, D. C., "Steam Cooled Breeder Reactors," B&W, presented at ANS Mtg., Detroit, Michigan, April 26-28, 1965.
5. Wright, J. H., et al, "Report of Reciprocal Exchange Trip to USSR, by U. S. Atomic Scientists," Nuclear Reactors in the Soviet Union, WASH-1060, December 11-22, 1964.
6. Baker, A., "A Direct Supercritical Steam-Cooled Fast Reactor of 500 MW(e) Unit Size," TRG Report 667(R), U.K.A.E.A., 1965.
7. Bishop, A. A., Sandberg, R. O., Tong, L. S., "High Temperature Supercritical Pressure Water Loop - Forced Convection Heat Transfer to Superheated Steam at High Pressure and High Prandtl Numbers," WCAP-2056, Part IV, November 1964.
8. Bishop, A. A., Sandberg, R. O., Rong, L. S., "Forced Convection Heat Transfer to Water at Near Critical Temperature and Supercritical Pressures," presented at Joint Meeting of AIChE and I Chem E, London, June 14-17, 1965.
9. Boyko, E. S., Cohen, P., et al, "High Temperature Supercritical Pressure Water Loop - Corrosion Tests," WCAP-2056, Part VI, August 1965.
10. Pearl, W. L., et al, "General Corrosion of Materials for Superheat Applications," GEAP-4760, March 1965.
11. Reynolds, M. S., "Strain Cycle Phenomena in Thin-Wall Tubing," GEAP-4462, January 1964.

APPENDIX A

A PICTORIAL PRESENTATION

OF THE

SAXTON SUPERCRITICAL LOOP

Work Performed

Under

AEC Contract AT(30-1)-3374

By The

Westinghouse Electric Corporation

Introduction

The advent of supercritical fluid cooled boilers for large central power stations has shown that there are economic advantages to this coolant over standard D&S or superheated steam power generation facilities. It is reasonable to expect that supercritical fluid can also be used as a nuclear reactor coolant, thereby imparting to this system the same economic advantages. These are:

1. High heat capacity per pound of pumped fluid.
2. High coolant outlet temperatures.
3. High steam temperatures and pressures resulting in higher cycle efficiencies and lower turbine generator costs.
4. Very good heat transfer properties.
5. A single phase fluid throughout the temperature range of the coolant.

Preliminary designs of supercritical water cooled ($T > 705^{\circ}\text{F}$, $P > 3206$ psia) reactor have indeed shown this promise to exist, but integral with this promise are a number of feasibility problems.

The Saxton In-Pile Supercritical Loop is a joint AEC-Westinghouse effort to help delineate the problems that do exist in the supercritical reactor concept. There are three problem areas where emphasis has been placed in the design of the Supercritical Loop:

1. Fuel element performance.
2. Mass transfer effects.
3. Water chemistry effects.

All data and post-irradiation analysis will be directed toward the delineation of these problems. The problems will be solved at their advent, if possible.

The following pages pictorially describe the design and construction of the Supercritical Loop. It is felt that this method of presentation will give the reader an appreciation of the magnitude and scope of effort that has been expended to date.

Containment Vessel Exterior

The Supercritical Loop is installed within the Saxton Reactor which is located at Saxton, Pa. The reactor is owned and operated by the Saxton Nuclear Experimental Corporation (SNEC). An experimental program aimed at developing advanced PWR concepts is jointly conducted by SNEC and Westinghouse. Shown is an overall view of the Saxton facility with the control building in the foreground and the containment vessel to the rear.

The following simplified flow diagram shows the similarity between the loop and the conditions in a supercritical water cooled, power reactor system. Representative coolant pressures and temperatures are shown for a bulk outlet temperature of 1000°F from the fuel assembly. The loop is constructed of 316 stainless steel or Inconel in the high temperature section, and 304 or 316 SS in the low temperature regions.

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The sample system schematic shows loop bleed penetrations where data on loop mass transfer and water chemistry effects will be gathered. The sample lines totally within the containment vessel will gather information on average crud levels at three key points in the loop. The sample line upstream of the deaerator will transmit actual coolant, samples outside of the containment vessel. Emphasis will be placed on H_2 , O_2 , and Cl levels during analysis. The sample lines before and after the demineralizer measure the demineralizer effectiveness.

SAXTON SUPERCRITICAL LOOP SIMPLIFIED SAMPLE SYSTEM

Supercritical Loop Package Placement

Figure 4

The major loop components were pre-fabricated into packages before installation within the containment vessel. The packages and other separate major components were placed throughout the containment because of extremely tight space limitations. Pictures of as-built and installed packages follow, with their order specified by loop coolant flow direction.

PLAN "B-8"

Supercritical Loop Package Placement

PLAN "C-C"

Supercritical Loop Package Placement

The pump package is shown with the second main loop pump and the standby pump not installed. The pump shown is of Union Pump Co. manufacture, triplex positive displacement type, with design conditions of 5500 psia outlet pressure at 15 gpm flowrate. The second main loop pump will be located on the shelf at the left-center of the photograph, and the standby pump on the same shelf to the right-center of the photograph.

The loop coolant is heated in the interchanger from 130°F to 755°F. It is here that the coolant changes from highly pressurized liquid to super-critical temperature fluid. The interchanger has three parallel paths of helically wound, annular coils. The interchanger must be totally insulated during service, see Page 16.

After the Interchanger, the supercritical water is heated further in an electrically powered Heater Package. The heater has three parallel paths, with flow in the annulus between the heater element and the outside pipe shell. Each pass has 14 heaters, with the flow passing over each heater in series. The maximum power output of the heater is 640 Kw at a fluid outlet temperature of 1030°F. The heater package is completely enclosed by 4 inch thick "Unibesto" insulation.

Power is directed to the heater by the electrical connection box. Copper bus bars were used with silver plated connectors to form the electrical feeder lines. The connection box is designed for 440 V, 3 phase service at 300°F.

The heater package is shown in its installed position. It is hung in an I-beam cradle, about four feet above the floor. This was the first, and most difficult, package to rig into the containment vessel. It was skidded horizontally through the containment vessel access hatch, put in a vertical orientation, let down vertically 30 feet, moved 15 feet horizontally over the Saxton main coolant pump, let down 30 more feet, turned to a horizontal attitude, and then lifted four feet onto the I-beam sling. It is a credit to the riggers that the job went smoothly.

The connection box is shown with the MI power cables installed. The electrical connection box requires cooling, and the ductwork coming from blower is shown in the bottom center of the photograph. The sample system letdown valves are shown in the upper left.

SAMPLE SYSTEM LETDOWN VALVES

SAXTON MAIN COOLANT PIPE

SAMPLE SYSTEM FLOW CONTROL d/p CELLS

ELECTRICAL CONNECTION BOX

EXISTING SAXTON AIR-HANDLER

CONNECTION BOX DUCTWORK

HEATER PACKAGE - INSTALLED

The supercritical water coolant design conditions at the inlet to the pressure tube are now 3600 psia, 975°F. The flow must go through the five feet thick wall, shown on the left of the photograph, between the primary compartment and the storage well areas of the containment vessel. All storage well piping, except the removable sections leading to the pressure tube, is located on the ledge behind the reactor head. All high temperature storage well piping is covered by metallic insulation which is not affected by boronated water. Welding was very difficult in this area due to close quarters and higher radiation levels. The pipe jumpers to the pressure tube are removed due to reactor refueling activities.

The pipe sections leading to and from the pressure tube, and the reactor head penetration are shown more clearly by this close-up photograph. The congested conditions are evident. All material in the storage well area is stainless steel or epoxy coated aluminum.

All pressure tube instrumentation is located on the operating deck, about 15 feet above the top of the storage well. Part of the reverse flow safety injection system, i.e. the flow orifice and d/p cell, are located on the level slightly below the operating deck. The air pressure regulators and storage tanks are for valves located in the storage well. The emergency condenser level control, LC-X2, is also placed at this level.

On the operating deck, next to the pressure tube instrumentation, are located three auxiliary systems: (1) the feed tank for mixing loop chemicals, (2) the demineralized water makeup for the loop, (3) the reverse flow safety injection control valve FIC-X3.

After leaving the pressure tube at 3500 psia and 1000°F, the coolant flows to the outer side of the interchanger. Here the supercritical water is cooled to 460°F, and again the transition point between supercritical temperature fluid and pressurized liquid occurs in the interchanger. The coolant flow then passes to the high pressure cooler, a helically wound tube-in-tube heat exchanger, through the letdown valve, and on to the low pressure cooler. This also is a helically wound tube-in-tube heat exchanger. The loop coolant is now near the turbine outlet conditions found in an actual power plant. Both the high and low pressure coolers are cooled by reactor plant component cooling water. The interchanger and all high temperature piping is completely covered by insulation. It can be seen by the photograph that space is very limited in the area around the exchanger and deaerator packages.

The coolant flows from the low pressure cooler to the deaerator, where any gasses formed in-pile are removed from solution. The deaerator tank, vacuum pump, and auxiliary systems are shown as-built in the WAPD shop. The deaerator package is located next to the exchanger package in the primary compartment, but due to space limitations it was impossible to make a good photograph of the package as installed. The top of the angle-iron frame supports the recombiner package, which recombines the H_2 and O_2 and returns it to the loop. It also collects all other non-condensable gasses, and sends them to the Radioactive Waste Disposal Facility (RWDF).

The loop coolant is pumped from the deaerator through the clean-up section of the loop by the condensate pumps. During regular loop operation, the pumps are connected in series. If only one pump is required or either pump fails, the flow is through only that pump and is controlled automatically by the check valves. Condensate pump outlet pressure and temperature are measured by PI-X24 and TRC-X2-6, respectively.

The condensate pump package was installed below the heater package in the primary compartment. The insulated pipe shown in the foreground is an expansion loop for line outlet of the heater package. The valves shown on the right are for the sample connection located after the heater package.

The coolant flows from the condensate package to the full-flow loop demineralizer. The two feet demineralizer and its lead shield are shown at the right. The demineralizer bypass valve HC-X6, and resin removal ball valve HC-X28 are shown. Three months continuous operation is expected for each resin charge. The resin can be charged remotely.

After demineralization, the loop flow is filtered to remove demineralizer resin fines and crud greater than 25 μ . A 5 μ filter is placed in parallel with the 25 μ filter, and it will be used for an undetermined time to remove all crud greater than 5 μ . The 3-way valve offers remote choice of filters. The d/p switch gives an alarm when the filter is plugged. The quick-disconnects are used in case of a fuel failure, i.e., when the filter package will probably have to be disposed of remotely. The package is designed to fit into a 55 gal. drum for burial. The coolant has now completely traversed the loop and now goes back into the suction of the pump.

The reservoir package contains one of the important loop auxiliary systems. Nitrogen gas is pressurized to 4400 psia by the nitrogen compressor. The pressurized gas is stored in the gas bottle. The compressed N_2 acts as the cushion above the accumulator, with remote fill and vent valves available. It also is used as the pressurizing gas for the safety injection system. It acts above the water level in the coolant reservoir.

The reservoir package is shown in place on a narrow shelf in the auxiliary compartment. The photograph shows the placement of the nitrogen reservoir bottle and the coolant reservoir. PC-X10 pressure switch controls the nitrogen pressure in a 4000-4400 psia range. The relief valve PSV-4 is set for 5000 psia.

Both the gas bottle and the coolant reservoir protrude below the support grating for the reservoir package. The coolant reservoir water level is monitored by d/p cell LIC-X6.

The safety injection control valves channel the coolant reservoir water to the loop under accident conditions. When FRC-XI opens, the water is injected down-stream of the pumps, and the loop flow is in the regular direction. FIC-X3 valve (shown in the operating deck photograph) will inject the water in the reverse direction through the pressure tube. After the coolant reservoir capacity is exhausted, LIC-X6 valve acts, and plant service water will be injected into the loop.

The head tank supplies NPSH for the main loop pumps and demineralized makeup water for the loop. It is hung from the ceiling in the primary compartment. This is the highest active portion of the loop, only the feed tank is higher.

SUPERCritical LOOP CONTAINMENT VESSEL PENETRATIONS

Shown are the Supercritical Loop containment vessel penetrations. MI cable is passed through specially designed fittings, sealed, and then leak checked. One continuous length of cable is routed from outside the containment vessel to junction boxes in the vessel. Jumper MI cable is then run to all instruments.

The Supercritical Loop has various auxiliary components and systems which are inside the containment vessel. The pressure tube is inserted into the reactor through the head nozzle. Thermal stress effects are minimized in the head nozzle by bleeding some of the reactor coolant up through the annular clearance between the pressure tube and the nozzle. The Reactor Nozzle Bleed Cooler system controls the bleed flow rate, cools the coolant, and lets down the pressure before putting the coolant back into the Reactor Cleanup System. Shown are the let-down valve FIC-X9 and the flow control d/p cell.

The Supercritical Loop requires the services of the Reactor component cooling water system for (1) the high pressure cooler, (2) the low pressure cooler, (3) the sample line coolers, (4) the vacuum pump seal water cooler, (5) and the recombiner condenser. The system contains chromated water and is cooled by river water heat exchangers. With the addition of the Supercritical Loop, the existing main CCW pump was overtaxed. A new pump was purchased and installed to rectify the situation. Its capacity is 260 gpm at 230 ft. of head vs. the original pumps 150 gpm at 105 ft. of head. The existing spare CCW pump was left in service.

Instrument air is required to energize the S.C. Loop's air operated solenoid and control valves, and to provide power for the diaphragm operated nitrogen compressor. The large compressor shown here has an 80 SCFM capacity at 125 psi output pressure. The small compressor, shown in Page 22, is powered independently, so it can act as an emergency backup.

The instrument air passes through a clean-up system before connection to the valves. There is an entrained water separator, an oil separator, and an automatic cycling air dryer package. This ensures that water does not collect in the valve operators. Reservoir tanks and check valves are placed on valves which must operate in an emergency.

Primary Compartment Air Handler

An additional air-handler was needed in the primary compartment due to increased heat load caused by the SC Loop Heater and Ex-changer packages. The air-handler was hung from the primary compartment ceiling, and the necessary air ducting was fabricated. Power was supplied in parallel with the existing Saxton air-handler, so no additional motor-starters and controls were needed.

After a fuel irradiation period is completed or if a fuel failure has occurred, the pressure tube and its contained fuel assembly must be stored in the spent fuel storage pit for a decay period. The pressure tube storage rack was fabricated for this purpose. There is room for two pressure tubes. The rack is now under 15 ft. of water in the fuel storage pit.

After the fuel assembly power has decayed to the required level, the fuel and baffle assembly is removed from the pressure tube. The baffles are cut off by an underwater saw. The rods are then placed in the failed fuel can and sealed under pressure. The can is designed to fit the WTR shipping cask. The fuel can then be moved to the Westinghouse Post Irradiation Facility for analysis.

Loop Power transmission and control equipment are located outside of the containment vessel. The main power supply to the loop is a 1500 KVA transformer furnished by Pennsylvania Electric Co. The input power to the transformer comes from the Saxton Power Plant switchyard.

The 640 Kw, 3 ϕ heater is controlled by the saturable core reactor. The input voltage to the heater is varied from 0 to 440 V by the loop temperature and flow control system to give a constant inlet temperature to the fuel assembly.

The Loop Motor Control Center (MCC) is located in the Saxton Reactor Control Building. The MCC contains most of the loop's secondary breakers and motor starters. These include the two main loop pumps, condensate pump A, the vacuum pump, the heater connection box blower, and the two air compressors.

The standby Loop Pump and Condensate Pump B power is derived from the Saxton Reactor Vital Bus. The vital bus is completely separate from any loop power supplies and is connected into the Saxton Reactor emergency power sources. This protects the loop from a loss of flow accident if loop power is lost.

Loop Control Panel No. 1 is located in the Saxton Reactor control room. This panel contains the annunciator, most of instrumentation controllers, and all of the valve and pump control switches. The two large controllers for the high and low pressure coolers are also located in Panel No. 1. This is the main control panel. Most of the controls required during emergency operation are located in Panel No. 1.

Control Panel No. 2 is also placed within the Saxton Control Room. This panel contains the two 16 point temperature recorders, the heater power recorder, the heater inlet and outlet temperature controllers, the sample flow recorders and controllers, and the radiation monitor.

The instrumentation rack is located behind the control panels. The rack contains the heater controller, instrumentation power supplies, square root converters, E-I converters, R-I converters, and alarm units. All control setpoints not necessary for emergency loop operation are located in the rack.

The main purpose of the Supercritical Loop is to test fuel under supercritical fluid conditions. The pressure tube, and its integral fuel assembly is inserted into the core through a penetration in the reactor vessel head. The pressure tube is a closed end tube with inlet and outlet nozzles welded to it. The pressure tube is completely made of 316 stainless steel.

Two fuel assemblies have been fabricated. The difference between assemblies lies wholly in the fuel rods. One assembly has pelleted UO_2 fuel and Incoloy 800 clad, while the other has vibratory compacted and swaged UO_2 with the Westinghouse 16-20 stainless steel as clad material. The miscellaneous fuel assembly parts and baffles are made from various corrosion resistant materials, such as Incoloy 800, 16-20 stainless steel, and 316 stainless steel.

The next three photographs show the pressure tube and its internals before assembly. Each picture shows a portion of the assembly, moving from the top which protrudes above the reactor penetration, to the bottom which is in the active core area.

The lower half of the first completed fuel assembly is shown. The dimples on the outside baffle of the fuel section ride on the inside wall of the pressure tube. Neutron streaming in the vertical direction is averted by the stainless steel streaming plug.

The upper end of the fuel assembly has the flow inlet and outlet plenums. The coolant flow is through the inlet openings shown, and down between the baffles. The flow is reversed at the bottom of the pressure tube, and then flows up through the fuel assembly and baffles, then out the upper plenum.

The final photograph shows the fuel assembly being inserted into the pressure tube. The fuel assembly is held in the pressure tube by jack screws and a conoseal gasket. The fuel assembly can be remotely removed from the pressure tube, if needed.