ENCLOSURE 1

Requested Additional Information Pertaining to SCE's Submittal on Dedicated Shutdown System for Fire Protection at SONGS 1 (Docket No. 50-206)

Q.1 Clarify how the following components and equipment needed for Dedicated Shutdown (DS) System are cooled in the absence of Component Cooling Water (CCW) and Salt Water Systems:

Q1.a North Centrifugal Charging Pump G-8A

Is the local bearing oil cooling fan powered by DS power supply (Enclosure 1, p.13) a totally self-contained cooling unit?

R1.a The bearing oil cooling fan associated with the North Centrifugal Charging Pump G-8A is a totally self-contained unit located immediately adjacent to the pump. The fan forces air through a cooling coil to remove heat from the charging pump bearing oil. The bearing oil is circulated through the coil from the charging pump's lube oil reservoir by an integral shaft-driven gear pump.

Power to the fan motor is normally supplied from 480 V MCC-2A. During operation of the Dedicated Shutdown System, power will be supplied from the DS diesel generator through a manual "no load" transfer switch. The transfer switch will disconnect the fan motor from its normal supply and connect it to the DS diesel generator supply.

Q.1b. RCP Thermal Barriers

You state that in the event both the CVCS and the CCW are unavailable due to a fire event (either the CVCS or the CCW can provide cooling water to the RCP thermal barriers), the thermal barrier pump can supply the needed cooling water to the RCP thermal barriers for 2 hours by which time the charging pump will be restored to operable status (Enclosure 1, p.13). Clarify whether in addition to the manual operation such as aligning the charging pump suction to the RWST and supplying dedicated power to the charging pump G-8A motor through a "dedicated manual transfer switch" (you have described these operations on p.16 of the enclosure), any repair is required to restore the charging pump G-8A to operable status (note that repair work is not acceptable to achieve hot shutdown).

R1.b In the event both CVCS and CCW are unavailable due to a fire, there are no repair actions required to restore the charging pump G-8A to operable status. The only fires which would cause the unavailability of both CVCS and CCW would, by design, not affect the availability of the DS system.

In the event of a fire in the charging pump room in which pumps G-8A and G-8B are both disabled, the DS System will not be used. Instead, the Safety Injection (SI) System will be used as an alternate shutdown system. Use of the SI system as an alternate shutdown system would involve depressurizing the reactor coolant system via the pressurizer power operated relief valves and injecting borated water from the Refueling Water Storage Tank (RWST) using the safety injection pumps in series with the main feedwater pumps. Reactor heat removal would be accomplished by the steam generators via natural circulation on the primary side and operation of the auxiliary feedwater system and atmospheric dump valves on the secondary side. With the reactor coolant system depressurized to 350 psig, cold shutdown would then be established and maintained using the Residual Heat Removal (RHR) system in its normal manner. Cold shutdown can be achieved in less than 72 hours by this method.

The use of the SI system as an alternate shutdown system represents a departure from the original DS system design concept presented to the staff in our April 24, 1984 submittal. The new approach is based on work performed subsequently in support of our Updated Fire Hazards Analysis Report which was submitted to the Staff with our letter dated February 11, 1985.

The availability of the SI system following a fire in the CVCS pump room, as well as the availability of the other normal systems required to operate in conjunction with the SI system to achieve cold shutdown, will be confirmed during the detailed design of the DS system by associated circuits analysis.

Q1.c Motor Driven Auxiliary Feedwater Pump, Thermal Barrier Pump

How are these pumps cooled?

R1.c

i. The Motor-Driven Auxiliary Feedwater Pump (G-10S) seals and bearing oil are cooled by feedwater tapped from an intermediate stage of the pump. The motor bearing oil is air-cooled by convection. The motor windings are air-cooled by an integral shaft-driven fan.

ii. The Emergency Thermal Barrier Cooling Pump (G-964) seals are cooled by controlled leakage. The bearing oil on the motor and the greased bearings on the pump are air-cooled by convection. The motor windings are air-cooled by an integral shaft-driven fan.

Q1.d Dedicated Diesel Generator

Clarify whether the cooling for the DS diesel generator (referred to on page 22 of Enclosure 1) is provided by a self-contained cooling unit? If so, describe it briefly.

R1.d The DS diesel generator will be cooled by a self-contained cooling unit. This will be a requirement specified in the diesel generator procurement specifications. It is expected that the cooling will be provided by a closed loop jacket water system, an engine driven circulating pump, and a radiator with an electric motor or engine driven fan for forced air flow through the radiator cooling coils. The actual cooling system configuration will be determined as part of the detailed design of the DS system.

Q1.e November 1982 SER identified that RC pump oil coolers, seal water heat exchanger, and letdown heat exchangers are also provided cooling water by CCW. Confirm whether this equipment is needed when the DS system is utilized to accomplish shutdown (Presumably, these are not needed and consequently unavailability of CCW will not compromise the DS capability to achieve shutdown?).

R1.e The RCP oil coolers, seal water heat exchangers, and letdown heat exchangers are not needed when the DS system is utilized to accomplish shutdown. During DS system operation, the reactor coolant pump motors are tripped, and the seal water return and letdown flow paths are isolated.

During normal operation, the prime function of the seal water heat exchanger is to cool seal water return flow. However, it is also used to cool charging pump recirculation miniflow. Because the recirculation flow is returned directly to the charging pump suction header, cooling is necessary to prevent the pump from overheating when demand for RCS make-up flow is low.

Because during DS system operation, the seal water heat exchanger is unavailable to provide this function, the DS system design will incorporate a modification that will permit the recirculation flow to be returned to the RWST. The RWST will serve as the heat sink for the recirculation flow during DS system operation. (This modification was not identified in our April 24, 1984 submittal.)

Q2. On pages 12 and 13 of Enclosure 1, you state that charging pump operation must be ensured within 2 hours. Clarify whether primary coolant inventory will be sufficient and therefore acceptable for approximately 5 hours after the reactor trip even without any charging flow for 5 hours?

R2. If the reactor coolant pump (RCP) seals remain intact, the primary coolant inventory is sufficient for five hours even without any charging flow. This 5-hour figure is the time it would take for the pressurizer to empty assuming 7 GPM leakage from the RCS. This assumed leakage rate corresponds to 2 GPM leakage from each RCP seal assembly plus 1 GPM leakage from "unknown sources." The 2 GPM RCP seal leakage figure is based on the pump manufacturer's seal assembly performance data. The 1 GPM leakage corresponds to the SONGS 1 Technical Specification limit for RCS leakage from unknown sources.

If the Technical Specification limit for the leakage from both known and unknown sources (6 GPM) is assumed, raising the total RCS leakage to 12 GPM, the time it would take for the pressurizer to empty is approximately 3 hours. However, in order to prevent the loss of seal integrity, the seals must be maintained at a temperature below 350°F. With the Chemical and Volume Control System (CVCS) unavailable to supply seal water to the RCPs, the seals are protected by the flow of component cooling water (CCW) to the RCP thermal barriers. If the CCW pumps are unavailable, the supply of cooling water to the thermal barriers can be maintained by the DC-powered Emergency Thermal Barrier Cooling Pump (G-964). However, when the Saltwater Cooling System is also unavailable, the operation of the thermal barrier pump is limited by the heat capacity of the CCW system. A calculation has shown that the system's heat capacity limit is reached in approximately 3 hours, when the system reaches a temperature of 200°F. For conservatism, operation of the thermal barrier pump is limited to two hours. Thus, for fire scenarios resulting in the loss of both normal seal injection (from CVCS) and saltwater cooling, charging flow to the seals must be restored by the DS system within two hours.

This two-hour time limit is considered to provide an adequate safety margin for restoring charging flow to the seals since the DS system design will permit the necessary operations to be accomplished in approximately 30 minutes. Also, the two-hour limit itself is considered conservative. If it were found necessary to operate the thermal barrier pump for an additional period of time, this would be possible by cooling the CCW system with water from the engine-driven screen wash pump.

The issue of RCP seal integrity during operation at high temperatures is also under study by Westinghouse. The results are still under evaluation, but they may show that the seals are capable of remaining intact at normal reactor coolant system operating temperatures for a period of up to 8 hours.

Q3. Emergency Diesel Generators

Q3.a Clarify whether station emergency diesel generator will be required to power any needed equipment for accomplishing safe shutdown when the DS system with its DS diesel generator is used.

R3.a The station emergency diesel generator will not be needed to accomplish shutdown when the DS system with its diesel generator is used. This is a part of the DS system design basis.

Q3.b On Page 9 of Enclosure 1, you state that in the event of a fire in the area of AFW pumps, the East Main Feedwater (MFW) pump provided by station emergency diesel generator can provide the feedwater to the SGs. State how this station emergency diesel generator is cooled.

R3.b Emergency Diesel Generator (EDG) #2 supplies power to the East MFWP via 4160 V bus 2C.

The diesel engine is cooled by a self-contained cooling unit, consisting of a closed-loop jacket water system, a lube oil heat exchanger, an engine-driven jacket water pump, and motor-driven fan coolers which are supplied by EDG via 480V Bus #2.

Q4. East Main Feedwater Pump G-3A

In case the East MFW pump G-3A has to be used to provide the needed feedwater to the SGs for achieving normal hot shutdown, where does the pump take its suction from? Does utilization of this pump require any manual operation? How is the cooling provided for this pump?

R4. The East MFW pump G-3A (operated in conjunction with the SG feedwater and atmospheric dump valves) is an alternate shutdown system which would be used in the event of an AFW pump area fire.

The availability of the East MFW pump following a fire in the area of the AFW pumps, as well as the availability of the other normal systems required to operate in conjunction with the East MFW pump to achieve cold shutdown, will be confirmed by associated circuits analysis.

When used as an alternate shutdown system, the East MFW pump G-3A will take its suction from the condenser hotwell by way of Condensate Pumps G-1A and B. Makeup to the hotwell is supplied from the Condensate Storage Tank (CST). Back-up sources of supply include the AFWST and the service water reservoir. The supply of water is controlled by hotwell level controller LC-16 which, upon sensing low hotwell level, opens 6" CV-20, the normal make-up valve, and upon sensing low-low level opens 8" CV-19, the emergency make-up valve. Should either valve fail to open on demand, manual bypass valves are available. Normally, however, no local manual actions are required to align and operate the East MFW pump. Operation of the pump and the feedwater and atmospheric dump valves can be accomplished from the Control Room.

The East MFW pump seals are cooled by flow supplied from the condensate pumps. The pump and motor bearing oil is cooled by a motor-driven fan cooler. A lube oil cooler, serviced by the Turbine Cooling Water System, is available as a back-up to the fan cooler. The bearing oil is circulated by a shaft-driven pump. A motor-driven auxiliary lube oil pump is available as a back-up.

Q5. Charging Pumps G-8A and G-8B

Q5.a. Clarify whether the spray shield/radiant heat shield proposed to be installed between the charging pumps G-8A and G-8B (refer to page 30 of Enclosure 1) constitutes the fire barrier between the pumps you mention about on page 13 of Enclosure 1.

R5.a The proposal to install a spray shield/radiant heat shield between the charging pumps G-8A and G-8B has been abandoned in favor of using the SI system as an alternate shutdown system for fires in the CVCS pump room. See our response to Question 1.b.

Q5.b With regard to the charging pump G-8B, provide information on the following:

- i What provides cooling for this pump (Is it CCW?)
- ii How is this pump motor powered?
- iii Should charging pump G-8A be disabled by a fire in the G-8A area, will the pump G-8B be used and reactor safe shutdown accomplished by the normal shutdown system (i.e., the RHR is available and will be utilized to achieve the cold shutdown)

R5.b i Charging pump G-8B seals are cooled by primary water tapped from the pump discharge. The pump bearing oil is cooled by a lube oil cooler serviced by the Component Cooling Water System. A self-contained fan cooler, described in the response to Question 1.a, is available as a back-up if CCW is not available. Power to the fan motor is normally supplied from 480 V MCC 2A.

The motor bearing oil is cooled by natural convection. The motor windings are cooled by an integral shaft-driven fan.

ii The motor for pump G-8B is powered from 4160 V bus 1C.

iii Should charging pump G-8A be disabled by a fire in the G-8A area, pump G-8B will be used and reactor safe shutdown accomplished by the normal shutdown systems. As noted in the response to Question 1.b, the Safety Injection (SI) system may be used as an alternative to the charging pumps in the event they are both disabled by fire.

Q6. November 1982 SER identified the addition of fire barriers between pumps for the CVCS, CCW, and RHR systems. In addition, the SER identified additions of enclosures and fire suppression for components of the CVCS and the AFW systems. Examine the plant modifications identified in the SER <u>item by item</u> to verify their applicability in the light of the proposed DS system.

R6. The plant modifications identified in the November 1982 SER are listed below with a statement of their applicability in light of the proposed DS system. The following statements are based on the conceptual design of the DS system only. The final scope of modifications necessary to meet Appendix R requirements will be determined during the detailed design of the DS system.

(1) Relocation of some components for the CVCS, CCW, and RHR systems.

Applicability. The DS system design is expected to make relocation of CCW and RHR components unnecessary. Certain components of CVCS may be relocated to provide post-fire access to certain control valves.

(2) Addition of fire barriers between pumps for CVCS, CCW, and RHR.

Applicability. The DS system design is expected to make the addition of fire barriers between the CVCS pumps, between the CCW pumps, and between RHR pumps unnecessary. In our April 24, 1984 submittal, it was proposed that a spray shield/radiant heat shield be installed between the CVCS pumps. However, this has since been determined to be unnecessary for Appendix R compliance. (See our response to Questions 1.b and 5.a for an explanation.)

(3) Addition of enclosures and fire suppression for components of the CVCS and AFW systems.

Applicability. The need to add enclosures and fire suppression for components of the CVCS and AFW systems will be established during the detailed design of the DS system.

(4) Relocation of electrical circuits for the reactor coolant system (RCS), CVCS, AFW, main steam system (MSS), saltwater cooling system, CCW, RHR, and the electrical power system.

Applicability. The DS system design is expected to make relocation of circuits for saltwater cooling, CCW, RHR, and the electrical system unnecessary. Circuits which are a part of the RCS (including PORV, block valve, group D pressurizer heaters, and certain RCS instrumentation), CVCS (including valve control circuits), and MSS (including SG level and atmospheric dump valve circuits) may require relocation.

(5) Addition of new electrical equipment to provide separation of the redundant switchgear.

Applicability. The DS system design makes the addition of new electrical equipment for separation of redundant switchgear unnecessary.

(6) Addition of circuit breakers, fuses, and/or isolation switches to isolate associated circuits.

Applicability. The DS system design minimizes the need for the addition of circuit breakers, fuses, and/or isolation switches to isolate associated circuits. However, some modifications of this type are expected.

(7) Addition of mechanical equipment in the CVCS, the AFW (the addition of a motor-driven pump), and the RHR systems.

Applicability. The design of the DS system makes the addition of mechanical equipment to AFW and RHR systems unnecessary. The installation of a third AFW pump is planned but for reasons other than dedicated shutdown capability.

The CVCS system will be modified to permit pump miniflow to be recirculated to the RWST. (See our response to Question 1.e for additional details.)

(8) Addition of a nitrogen backup system.

Applicability. The nitrogen backup system discussed in the SER is not necessary for implementation of the DS system. The need for nitrogen as a backup for valve control for the DS system is discussed in Section 4.0 of Enclosure 1 to our April 24, 1984 submittal.

Q7. November 1982 SER identified the addition of a new motor-driven AFW pump. Clarify how the proposed DS system eliminates the need for the additional motor-driven AFW pump for Appendix R analysis. (Please note that this is strictly in relation to Appendix R considerations. For example, the need for the new motor-driven AFW pump may arise due to other considerations such as a line break in the steam supply line to the turbine of the turbine- driven AFW pump coincident with a single failure i.e., failure of the motor- driven AFW pump.)

R7. The DS system design eliminates the need to add a new MDAFW pump because it provides a means of operating the existing MDAFW pump in the event of a fire which could cause the normal power to both the MDAFW pump and the main feedwater pumps to become unavailable. For a fire in the area of the AFW pumps, the East MFW pump G-3A can be used as an alternate shutdown system (see our response to Question 4).

Q8. On pages 7 and 19 of Enclosure 1 you state that AFW will be supplied by the Auxiliary Feedwater Storage Tank (AFWST). On page 17, you further state that water stored in the AFW and condensate storage tanks will supply AFW to the SGs. Clarify whether the suction of the Auxiliary Feedwater Pump includes CST also.

R8. The AFWST will provide the initial source of water to the MDAFW pump. When the AFWST is depleted, the MDAFW pump will be supplied by the CST via an existing line between the CST supply header and the MDAFW pump suction header.

Q9. How do you propose to support the static water loads in a small segment of the main steam line and the steam supply line to the turbine of the turbine-driven AFW pump, when these lines carry water to be letdown to the outfall point?

R9. Detailed evaluation of the affected piping and supports will be performed during detailed design of the DS system. Any modifications required as the result of this detailed evaluation to ensure that the lines are adequately supported will be implemented.

Q10. With regard to Figure 3-1 of Enclosure 1, provide the following:

Q10.a Mark CV-113 and the existing manual isolation valve referred to on page 7 of Enclosure 1. Clarify whether the manual isolation valve referred above is the 3"-600-129 manual turbine isolation valve referred on page 17 of Enclosure 1?

R10.a The manual isolation valve referred to on Page 7 of Enclosure 1 is the 3"-600-129 manual turbine isolation valve referred to on page 17 of Enclosure 1. However, on P&ID 5159570-0, which was current at the time, there were two valves designated 3"-600-129, one upstream of CV-113 and one downstream of CV-113. P&ID 5159570-0 has since been superseded by P&IDs 5178221-0 and 5178225-0. On the new P&IDs, these valves have been assigned unique tag numbers. The valve upstream of CV-113 appears in 5178225-0 and is designated MSS-333. The valve downstream of CV-113 appears in 5178221-0 and is designated AFW-356. It is the valve <u>downstream</u> of CV-113, AFW-356, which was intended to be utilized as part of the DS system by providing a positive means of isolating the TDAFW pump turbine when the steam supply line is utilized for feedwater letdown.

Q10.b From the outfall point, where does the water go and <u>get collected</u>?

R10.b The outfall point will be determined as part of the detailed design of the DS system. The following alternatives are currently being considered:

(1) The circulation pit at the seawall either directly or via a pipe connection to the outlet of the turbine plant cooling water heat exchanger.

(2) The Circulating Water System forebay

From either of these outfall points, the water is discharged to the ocean.

Q10.c On page 9 of Enclosure 1, the motor-operated supply valves to the charging pump suction header are identified as LCV-1100 C and D. However, in Figure 3-1, these are identified as LCV-1100 B and D. Which is correct?

R10.c The RWST supply to the charging pump header isolation valves are LCV-1100B and LCV-1100D. Figure 3-1 is correct.

Q10.d On page 16, the AFW system flow control valves are identified as FCV-2300, 2301, 3300, and 3301. However in Figure 3-1, these are identified as FCV-3200, 3201, 3300, and 3301. Which is correct?

R10.d The AFW system flow control valves are FCV-2300, -2301, -3300, and -3301. Page 16 of Enclosure 1 (of our April 24, 1984 submittal) is correct.

Q11. Instrumentation and Controls

Q11.a CST, RWST, AFWST level indications

Page 25 of Enclosure 1 states that level indication is not required for CST, RWST, or AFWST. However, Reference 6 that you have referred to explicitly states that level indication should be provided for all the tanks that are needed for achieving safe shutdown. For example, Reference 6 mentions specifically CST and RWST. The Table 3-1 of Enclosure 1 also does not list these tanks. Since these tanks will be utilized when DS system is used, explain how you propose to provide level indications for these tanks?

R11.a Level indication will be provided for the CST, RWST, and AFWST as follows:

(1) Level indications for the CST will be provided by a local pressure indicator. This indicator will be added as part of the DS System design.

(2) Level indication for the RWST will be provided by an existing float-type indicator.

(3) Level indication for the AFWST will be provided by an existing float-type indicator.

Q11.b AFW Supply and letdown flow indications

On page 21 of Enclosure 2 you state that the desired AFW flow rate is established through the coordinated action of the operators of the supply and letdown valve station and subsequently the flow is controlled at the letdown line alone. Also Reference 6 you have referred requires that diagnostic monitoring should be provided. On page 25 of Enclosure 1 you state that AFW flow indication is desirable but not absolutely necessary for the operation of the DS system. Table 3-1, however, includes AFW pumps flow at the location of the AFW "throttle valves" (are these FCV 2300, 2301, 3300, and 3301 shown on Figure 3-1?) as a new modification. Clarify whether the <u>indication</u> of the AFW flow rate for the SGs will therefore be provided as a modification? The Table 3-1 also shows radioactive effluent monitor will be provided at some location in the AFW letdown line. Clarify whether the <u>indication</u> of the letdown flow rate, i.e., the flow rate of feedwater from the SG (via the steam supply line to the turbine of the steam driven AFW pump) to the outfall point, will also be provided as a new modification. It looks as though "Radioactive Effluent Monitor" listed in Table 3-1 should have been Auxiliary Feedwater letdown flow. Check this entry.

R11.b i AFW Flow Indication

The DS System will include the addition of local indicators for AFW flow to each steam generator. The indicators will utilize existing flow elements FE-3453, FE-3454, and FE-3455 and share taps with existing AFW flow transmitters. During DS system operation, the flow indicators will aid the operator assigned the valve station to balance AFW flow to the steam generators while keeping total flow within operating limitations of the pump.

ii AFW Throttle Valves

The "AFW Throttle Valves" noted in Table 3-1 refer to FCV-2300, -2301, -3300, and -3301. See the response to question 10d for clarification of a valve numbering error made in Enclosure 1.

iii Letdown Flow Indication

The DS System will not include an indicating device for "letdown" flow from the steam generators. This is unnecessary since indication of AFW flow to the steam generators is already being provided as part of the DS system.

iv Radioactive Effluent Monitor

The DS system will include provisions for monitoring the radiation level in the effluent discharged from the steam generator letdown line. The equipment will be mobile and installed post-fire, but prior to initiating the single-phase portion of the cooldown.

Q11.c On Page 3 of Enclosure 1, you state that the DS system approach offers the advantage of using a single system and a single procedure for any fire which would cause the normal systems to be unavailable. Obviously one category of fire events will involve utilizing the DS system when the RHR is available for achieving cold shutdown. This means that RHR pressure and flow indication should be available in the remote shutdown panel which according to you is an integral part of your DS system. In this context, note that the November 1982 SER identified that instrumentation will be available at the remote shutdown panel for RHR flow. Explain how you propose to provide RHR pressure and flow indications which may be needed during DS system utilization.

R11.c In the event of a fire which disables all normal systems <u>including</u> RHR, the DS System would be used for 72 hours and beyond until completing any repair procedures necessary to restore RHR to an operable status and placing the system into operation. In the event of a fire which disables all normal shutdown systems except RHR (in which case RHR pressure and flow indications would be available from the control room), the DS system would again be used, and again only until normal RHR operation could be initiated (from the control room).

With no repair actions necessary to restore RHR to an operable status, it would be possible to use the RHR system to achieve cold shutdown. Procedurally, operation of the RHR system for fire events which do not disable it can be handled as a branch path within the DS System operation procedure. However, regardless of the initial availability or unavailability of the RHR system, since cold shutdown can be achieved within 72 hours without RHR, it is not necessary to have RHR pressure and flow indication available on the remote shutdown panel. Therefore, these indications will not be provided as part of the DS design.

In response to Questions 1.b, 4, and 5.a, we identified systems (SI, MFW) that would be used as alternate shutdown systems in the event of fires affecting the availability of the CVCS or AFW systems. This is a necessary departure from our original DS system design philosophy since fires affecting CVCS and AFW affect not only normal shutdown capability, but dedicated shutdown capability as well.

Therefore our original objective of providing "...a single system and a single procedure for any fire..." has been modified to recognize that certain fires will require the use of alternate shutdown systems and alternate procedures.

Q11.d On Page 21 of Enclosure 1, you state that at the remote shutdown panel T_{hot} signal is available, but its indication is unavailable. Since Reference 6 requires the indication of T_{hot}, explain how you propose to make this available.

-R11.d We indicated in our April 24, 1984 submittal that T_{hot} and T_{avg} signals were available at the Remote Shutdown Panel (RSP). A subsequent physical inspection of the RSP revealed that these signals were not present. However, a T_{hot} indicator will be added to the RSP as part of the DS system design.

Q12. Primary Coolant Pressure Control

Q12.a On Page 14 of Enclosure 1, you state that a "bubble" can be maintained in the pressurizer without heaters for the postulated cooldown period. Explain what "bubble" referred to above means and also what is the postulated cooldown period? Clarify whether the natural pressure control (i.e., not injecting the "hard bubble" (nitrogen bubble) or not activating the pressurizer heater Group D) is maintaining the "bubble" referred to above.

R12.a i <u>Bubble</u>. The "bubble" mentioned on Page 14 of Enclosure 1 refers to the steam space in the pressurizer. During normal operations, the steam space in the pressurizer regulates primary system pressure by providing a compressible medium for absorbing changes in liquid volume. The steam space is controlled by a combination of spray and electric heaters. Overpressure protection is provided by the power operated relief valves and code safety valves.

ii <u>Postulated Cooldown Period</u>. The postulated cooldown period referred to on Page 14 of Enclosure 1 refers to the 72-hour period of time within which 10CFR50 Appendix R requires a nuclear plant to be in cold shutdown following any postulated fire.

iii <u>Pressure Control During Cooldown</u>. In our April 24, 1984 submittal we indicated that during cooldown, RCS pressure would be controlled by maintaining a bubble in the pressurizer. The bubble, in turn, would be maintained without the use of heaters or sprays since the pressurizer cooldown rate is slow in comparison with the RCS cooldown rate. We also indicated that a PORV and the code safeties would be available for overpressure protection, and that a PORV would be manually operated to avoid NDTT limits during the cooldown period.

Subsequent to our April 24, 1984 submittal, the need for additional pressure control capability during cooldown was re-evaluated. It was determined that pressurizer heaters should be available during the cooldown period. Heaters could be required to recover from the following conditions:

- accelerated cooldown of the pressurizer resulting from excessive pressurizer level fluctuation during the cooldown period.
- accelerated cooldown of the pressurizer resulting from abnormally high or low initial pressurizer level.
- accelerated cooldown of the pressurizer resulting from failed or moisture-impregnated insulation.
- excessive energy/mass losses from the pressurizer resulting from PORV operation during the cooldown period.

The DS system design originally incorporated provisions to recover pressurizer heater group D by taking repair actions after reaching cold shutdown. The DS system design will now additionally incorporate cable replacement/rerouting between pressurizer heater cabinet #2 and the group D heaters which will permit the group D heaters to be recovered <u>without repair action</u> within one hour of reactor shutdown.

With this upgrade of the pressurizer heater circuit incorporated into the DS system design, the modifications proposed for injecting nitrogen into the pressurizer during cold shutdown will be abandoned. The heaters can be used during cold shutdown to maintain system overpressure in place of the "hard bubble" described in our April 24, 1984 submittal.

Q12.b Clarify whether injecting a nitrogen bubble or activating pressurizer heater group D may be needed only after the RCS temperature (T_{hot}) reaches 200°F (please see the bottom paragraph of page 14 and the top lines of page 15).

R12.b The proposal to incorporate into the design of the DS System the capability to inject a nitrogen bubble into the pressurizer has been abandoned. Pressurizer heater group D will be upgraded to permit operation in conjuction with the DS system within one hour of reactor shutdown. Thus, heaters will be available during RCS cooldown as well as during cold shutdown. (See also our response to Question 12.a.)

Q12.c On page 15 of Enclosure 1, you state that only if normal pressure control can not be recovered, the options mentioned above may be needed. Also, explain how you will maintain the bubble when no heaters are used especially when the pressurizer PORVs may be utilized for steam venting.

R12.c

i <u>Recovery of Normal Pressure Control</u>. Depending upon the location of the fire and the extent of fire damage to the normal pressurizer control systems, normal pressure control may be recoverable through repair actions taken after the fire has been extinguished and the affected areas are accessible.

As discussed in our response to Questions 12.a and 12.b, pressurizer heater group D will be upgraded to permit operation in conjunction with the DS system within one hour of reactor shutdown. The design will be such that a fire affecting the availability of heater group D will not affect the availability of the balance of the normal pressurizer heater circuits and vice-versa. The need for these modifications were identified subsequent to our April 24, 1984 submittal.

ii <u>Pressure Control During Cooldown</u>. See the response for Question 12.a.

iii <u>Pressure Control During PORV Operation</u>. If a pressurizer PORV is opened to vent steam from the pressurizer during cooldown, both pressurizer level and pressure will be monitored to determine when to reclose the valve. In the event the PORV fails to re-close, the associated block valve will be used to isolate the flow path. In the event excess mass and energy are released from the normal pressurizer during PORV/block valve operation, charging pump flow will be increased to restore level and pressurizer heaters to restore pressure.

Q13. Calculation Section - Pages 1 through 84

Q13.a On Page 3 (calculation section), you state that one of the options for removal of the heat from the RCS to achieve cold shutdown is utilization of the main feedwater system as a source of cooling water. Does this mean that RHR can be disabled concurrent with motor-driven AFW pump being disabled?

R13.a RHR can be disabled concurrent with the normal systems required to operate the MDAFW pump but not concurrent with the dedicated system required to operate the MDAFW pump.

The East main feedwater (MFW) pump is mentioned as an alternate to the MDAFW pump in the event of fire in the area of the MDAFW pump itself. This is discussed in the response to Question 4.

Q13.b On page 6 (calculation section), you state that the feedwater supply line and the blowdown line are both available for admitting cooling water into the active steam generator(s). What is the blowdown line referred to above? Is this the steam generator blowdown line?

R13.b The blowdown line referred to on page 5 of the calculation section is the steam generator blowdown line.

Q13.c On page 5 of 84, you state that pressurizer heaters are tripped and are no longer available. When will the pressurizer heater group D be restored? How will it be restored? (Will it be by manually operating the to-be-installed transfer switch to supply power from the DS system?)

R13.c In the event of any fire which would disable normal pressurizer heater control, the DS system will make it possible to restore power to and operate pressurizer heater group D within one hour of reactor shutdown. This will be accomplished without taking repair action.

Power will be restored to pressurizer heater group D from the DS system by manually operating the to-be-installed transfer switch. The heaters will then be manually controlled from pressurizer heater cabinet #2.

Q13.d On page 74 (calculation section), you state that if there is a need to accelerate the depressurization after the 35th hour it can be done by the use of the relief valves and/or the pressurizer spray. However, on page 5, you state that pressurizer spray is tripped at time zero of the fire event and is no longer available. Also, on page 8 of Enclosure 1, you refer only to pressure relief by PORV/block valve combination. Clarify whether the pressurizer spray will ever be used for pressurizer relief following a fire event.

R13.d Pressurizer spray system is not part of the DS system and need not be operable to accomplish shutdown using the DS system. In the event of a fire which disables the pressurizer spray system, depressurization of the primary system will be achieved using the pressurizer power-operated relief valve (PORV) CV-530.

In the event of a fire which does not disable the pressurizer spray system, the auxiliary spray, supplied from the charging system, may be used. Procedurally, this will be handled as a branch path within the DS system operating procedure or by an alternate shutdown procedure.

Q13.e On page 8 of Enclosure 1 you state that during the initial hours of the RCS cooldown, pressurizer heaters are not necessary and pressure may have to be relieved from the system by utilizing PORV/block valve combination. On page 74 (calculation section) you, however, state that under certain circumstances (for example, mixing at the surge line or if the initial water level is less than the normal water level) there may be a need for external pressurization. Explain this apparent discrepancy. Also state how you will pressurize if it is needed during the initial hours of RCS cooldown.

R13.e See our response to Question 12.a.

Q13.f On page 73 (calculation section), you state that the required degree of subcooling to prevent the void formation in the upper head is marginally maintained during the early part of the cooldown (up to the 8th hour). Examine whether the safety margin available up to 8 hours after a fire occurs provides reasonable assurance against void formation in the upper head up to 8 hours.

R13.f According to Westinghouse's St. Lucie study (Reference 1 in the Calculation section) the reactor head cools down at a rate of between 10 to 25° F/hr depending on the availability of CRDM fans. Even the minimum rate of 10° F/hr is faster than the pressurizer cooldown rate of approximately 2° F/hr. Consequently the safety margin to prevent void formation in the upper head is at least equal to the safety margin available at the shutdown initiation. This corresponds to nearly 50° F subcooling and is considered adequate.

Q13.g On page 73 (calculation section), you state that beyond the 35th hour the primary system pressure exceeds the null ductility pressure limit and stays above that limit for the rest of the cooldown. On page 74, you state that there is an obvious need to accelerate the depressurization after the 35th hour in view of the above consideration. You further state that this can be done by use of relief valves and/or the pressurizer spray. On page 8 of Enclosure 1 it is stated that a nitrogen bubble will be established to preserve the system overpressure or one group of pressurizer heaters (Group D) will be restored to maintain the system overpressure. Explain this apparent discrepancy.

R13.g The statements made on pages 73 and 74 of the calculation section, concerning the need to accelerate the depressurization after the 35th hour, pertain only to the cooldown phase of the operation, whereas the statements made on page 8 of Enclosure 1 concerning the need for nitrogen or heaters to maintain overpressure pertain to the operation only after the unit has reached cold shutdown.

Q14. Miscellaneous

Q14.a With regard to your commitment to provide additional information (see page 2 of your letter dated April 24, 1984), please provide, in addition to what you have committed, the following:

i Detailed description of how safe shutdown will be accomplished for a fire in each one of the fire areas. Provide this information <u>area by area</u>.

ii Detailed associated circuits analysis to reflect the utilization of the DS system. This analysis should encompass all the problems that may arise due to a fire in any fire area. Your analyses should address the problems that may arise due to 1) common bus including high impedence faults, 2) common enclosure, 3) spurious signals particularly those that involve high/ low pressure interface, and 4) electrical isolation deficiency.

<u>High Impedence Faults</u>

Provide assurance that the <u>total</u> of hot shorts associated with the <u>non-safe shutdown loads</u> supplied by a <u>common bus power supply</u> (also supplying safe shutdown loads) does not result in the opening of a circuit breaker associated with the common power supply, thus causing loss of power supply to the safe shutdown equipment and/or components <u>prior to</u> the individual breakers of the associated non-safe shutdown loads opening due to the fire damage.

<u>Electrical Isolation Deficiency</u>

Fire in certain areas (for example, the control room) may necessitate operating transfer switches (to transfer power and control from the control room to alternate shutdown systems) <u>prior</u> to the fire in the area damaging the control circuits and resulting in blown fuses. The staff does not give credit for operating the transfer switches prior to fire damage resulting in blown fuses. Also, the staff does not give credit for replacement of the blown fuses to achieve and maintain alternate hot shutdown (this is regarded as a repair and the staff's guidelines do not permit repair to achieve and maintain hot shutdown). To handle the potential for the electrical isolation deficiency in the design described above, review your electrical design and provide a drawing of all transfer switch designs in your plant. You should provide assurance that a blown fuse as a result of fire damage will not require replacement to achieve and maintain alternate hot shutdown (this can be done by modifying existing transfer switches if there be need for it and/or installing new isolation switches where necessary to provide redundant fusing).

R14.a i An area-by-area safe shutdown analysis will be generated as part of the detailed design of the DS system and provided to the NRC at that time.

ii A detailed area-by-area associated circuits analysis reflecting the utilization of the DS system will be generated as part of the detailed design of the DS system and provided to the NRC at that time. This analysis will address four problem areas noted in the question.

Q14.b Will the positive displacement charging test pump referred to by your FSAR be ever used for achieving safe shutdown following a fire event?

R14.b The positive displacement charging test pump will not be used for achieving safe shutdown following a fire event.

Q14.c Figure 3-1 shows the valve CV-530 in series with the pressurizer PORV CV-546; also the valve CV-545 is in series with the block valve CV-531. What are the functions of these valves CV-531 and CV-545? Will they also be used in the shutdown procedures?

R14.c CV-545 and CV-546 are the pressurizer power-operated relief valves (PORV). They operate to provide overpressure protection to the RCS. As part of the DS system, CV-546 is used to accelerate the rate of RCS depressurization when needed to maintain the system within the desired depressurization envelope. CV-545 is not used.

CV-530 and CV-531 are pressurizer PORV block valves. CV-530 is in series upstream of CV-546; CV-531 is in series upstream of CV-545. (Figure 3-1 of Enclosure 1 shows the valves incorrectly.) The block valves are provided as a means of isolating flow from the pressurizer in the event the respective PORV failed to close. As part of the DS system, CV-530 is used as a means of blocking CV-546. CV-545 is not used.

ENCLOSURE 2

CALCULATION/PROBLEM COVER SHEET

Calculation/Problem No: TH1

Title: DEDICATED SAFE SHUTDOWN SYSTEM

Client: SCE Project: SONGS-1

Job No: 0310-027-1372

Design Input/References: STATED WITHIN

Assumptions: STATED WITHIN

Method: STATED WITHIN

Remarks: THE JOB NUMBER SHOULD READ 0310-027-1372 INSTEAD OF 0310-027-1373 ON ALL PAGES

REV. NO.	REVISION	APPROVED	DATE
0	ORIGINAL		4/13/84
1	AFWP CAPACITY REVISED		4/22/85

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REVISION 1

The purpose of Revision 1 calculation is to incorporate the effects of reduced auxiliary feedwater flow and increased RCS leakage criteria. These changes were requested by SCE as described in the Impell proposal B/P 31-159, dated April 2, 1985. The changes consist of:

1. Maximum flow achievable by the motor driven auxiliary feedwater pump G-10S is 375 gpm instead of 400 gpm used in the original calculation.

2. In addition to the 7gpm RCS leakage through the pump seals and unknown sources, there is also 5gpm leakage from the known sources. Accordingly, the total RCS leakage rate is 12 gpm instead of 7 gpm used in the original calculation.

3. Cold shutdown condition is defined as 200°F average reactor coolant temperature. The original calculation was based on 190°F average RCS temperature as a conservative measure to compensate for uncertainties in

the steam generator heat transfer coefficient.

The calculation is revised reflecting these changes and their effect on the length of time to achieve cold shutdown, cooling water consumption and charging system requirements.

Revision 1 calculations affect the pages 2, 2A, 2B, 53, 60, 64 64A through 64L, 65, 65A, 65B, 76, 78 and 84.

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1.0 INTRODUCTION

The purpose of this calculation is to determine the feasibility of establishing and maintaining cold shutdown at SONGS 1 by using one or more steam generators in conjunction with a source of cooling water, such as the Main or Auxiliary Feedwater System for the removal of heat from the Reactor Coolant System. If shown to be feasible for SONGS 1, then the design of a dedicated safe shutdown system to meet requirements of 10CFR50 Appendix R would not be required to include provisions for RCS cooldown by way of forced circulation of the primary coolant through the Residual Heat Removal System

2.1 Approach

Mass and energy balance calculations are performed for the major primary and secondary system components which are essential for achieving and maintaining the cold shutdown. Consideration is given to constraints and limitations imposed by:

- Technical specifications
- Pressurizer steam bubble
- Possibility of voiding in the reactor vessel
- Available inventory of:
  - condensate
  - seal water make up
  - boric acid make-up
- Maintenance of an adequate natural circulation for the transport of the decay heat and stored thermal energy from the primary system

The calculation has combined these constraints to determine the acceptable and achievable cooldown rates using the steam generators as the only heat sink.

2.2 ASSUMPTIONS

The major assumptions used in this calculation are:

1. The reactor is initially at full power

2. At time equals zero:
   - the reactor is tripped with all rods inserted
   - reactor coolant pumps are tripped
   - pressurizer heaters and spray are tripped and are no longer available
   - Letdown is isolated
   - Turbine is tripped
   - Decay heat removal is initiated via the steam generators and atmospheric dump valves

3. At time greater than zero:
   - The RCS is intact except for reactor coolant pump seal leakage
   - The RCS pressure, temperature and pressurizer level vary from their normal initial values as a function

of mass and heat addition/extractions

- The charging system is making up through the reactor coolant pump seals and either a normal or safety injection flow path to make-up for mass losses due to seal leakage and volume contraction due to cooldown.
- The steam generator secondary side is isolated, except for cooling water supply and atmospheric dumps
- Residual Heat Removal system is not available
- The feed water supply line and the blowdown line are both available for admitting the cooling water into the active steam generator(s)
- Boron injection is provided from the Refuelling Water Storage Tank which has a Boron concentration of 3750 ppm.

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3.0 ANALYSIS

In the following section the parameters that are essential to achieving cold shutdown are calculated. These calculations are performed based on the assumptions stated in the preceeding section.

A schematic of the system being considered is given in Figure 3-1. Rather than attempting to present the full details, this figure presents interconnection of basic components and the coolant flow.

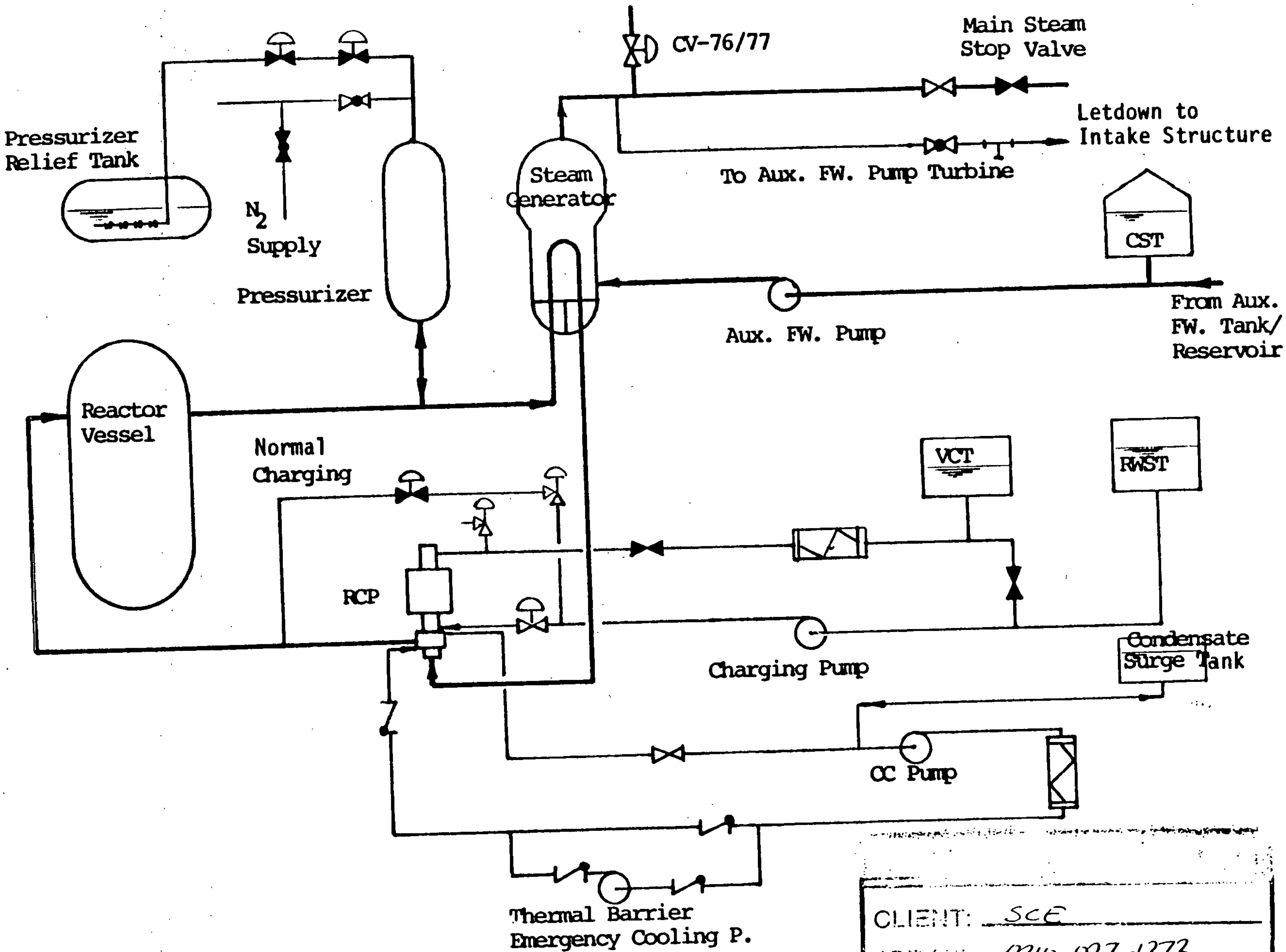

FIGURE 3-1 - SYSTEM SCHEMATIC

CLIENT: SCE

JOB NO: 0310-027-1373

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3.1 Decay Heat Rate

The decay energy release following the reactor trip was obtained from Reference 2 and is plotted in Figure 3-2 on the following page. The integrated decay energy release is also shown on this figure. The integrated decay energy release has been obtained from Reference 3.

Time (hr.)	Decay Heat (10^6 Btu/hr)	Interval Avg. (10^6 Btu/hr)	Integrated Decay Heat (10^6 Btu)
1/6	248		
		94	
1	73		93.8
		66	
2	58.5		
		53	
4	48.2		
		47	
5	45.4		
8		42	426
10	37.9		
24		34	961
25	29.1		
		28	
32	27.1		
36			
		25.3	1290
48			1584
50	23.5		
		21	
100	18.5		
		17	
150	15.7		
168			3760

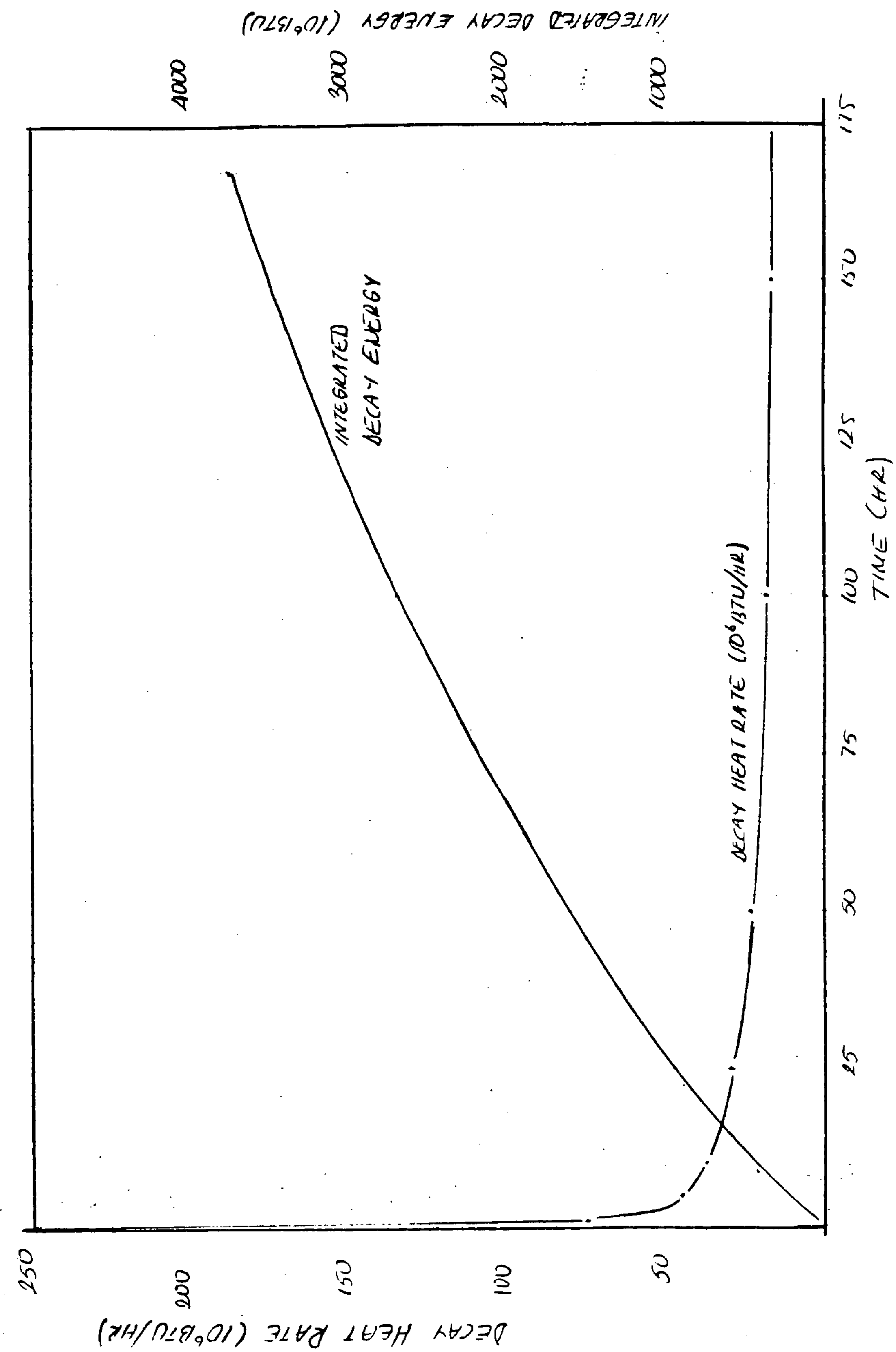

FIGURE 3-2 – DECAY HEAT TRANSIENT
(FOR TIME BEYOND 175 hrs SEE FIGURE 3-6)

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3.2. Stored Heat

In order to achieve cold-shutdown the steam generators must remove not only the decay heat but also the stored head in the primary system. This amounts to,

$$\dot{q}_{ST} = (M_w C_w + M_s C_s) \frac{dT}{dt} = C \frac{dT}{dt}$$

where,

M = Mass (lb)
C = Specific heat, Btu/lb-°F
$\dot{q}_{ST}$ = Stored heat removal rate

From Reference 3, p:17

$M_w = 3 \times 10^5$ lb
$M_s = 2 \times 10^6$ lb

Using,

$C_w = 1$ Btu/lb
$c_s = 0.11$ Btu/lb-°F

$$C = 3\times10^5\times1 + 2\times10^6\times0.11 = .52\times10^6 \text{ Btu/°F}$$

$$\dot{q}_{ST} = .52\times10^6 \frac{dT}{dt}$$

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3.3 Upper Head Voiding

During the natural circulation cooldown, the reactor upper head region is relatively stagnant and cools down at a much slower rate than the rest of the system. As a consequence of this void may form in the upper head region if cooldown and depressurization rates are not properly selected.

The possibility of voiding in the upper head has been investigated by Westinghouse and the findings and recommendations are given in Reference 1. Based on the conservative assumptions that:

- The upper head is initially at the hotleg temperature,
- The control rod drive mechanism (CRDM) fans are not available to assist cooling of the head externally,

the referenced document predicts an upperhead cooldown rate of 10°F/hr and recommends that the primary system cooldown rate should not exceed 25°F/hr in order to prevent void formation. The 25°F/hr cooldown rate is further

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subjected to constraints set by the subcooling requirements.

The recommended cooldown rate of Reference 1 is illustrated in Figure 3-3 until the point where RHR system can be put into operation. If the natural circulation cooldown is to be continued it must be realized that the cooldown rate is limited by the upper head cooldown rate which is approximately 10°F/hr according to Reference 1. In this study beyond 30th hour cooldown has been continued at approximately 5°F/hr until cold shutdown is achieved.

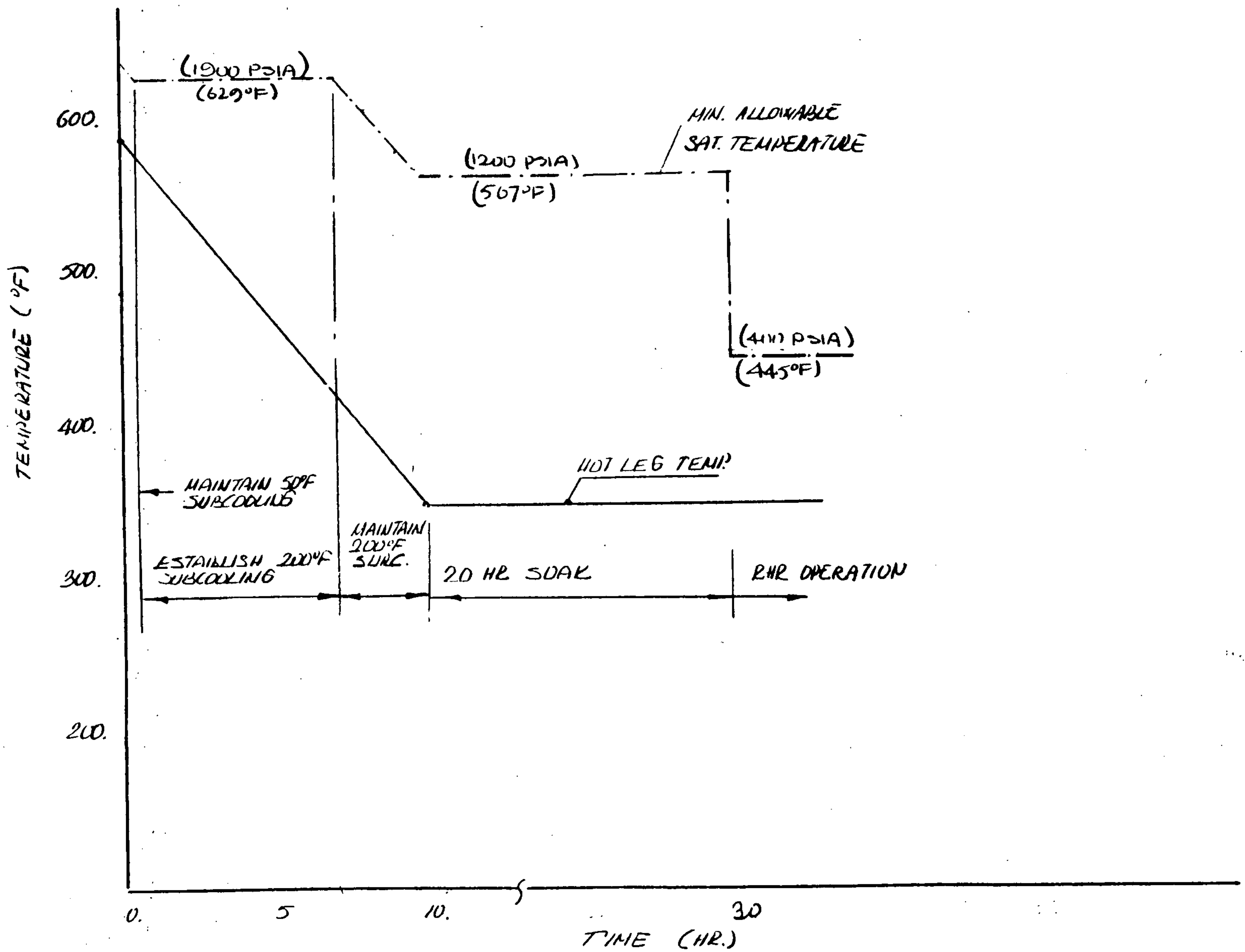

FIGURE 3-3 – RCS COOLDOWN RATE TO PREVENT VOIDING

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3.4 Pressurizer Cooldown Rate

The pressurizer cooldown rate is important for maintaining the proper primary system pressure which in turn controls the pressurizer steam bubble, reactor vessel upper head voiding in nill ductility requirements. The cooldown rate is determined by assuming that:

- Pressurizer water and steam are in thermodynamic equilibrium,
- Pressurizer heaters, spray and relief valves are not available
- Cooling due to the in-surge at the hot leg is negligible.

The first two assumptions are well justified. The third assumption may become invalid depending on when during the shutdown and how much in-surge takes place.

With these assumptions and the pressurizer data as given on the following two pages the cooldown rate is determined from the energy balance for the pressurizer:

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$$\frac{d}{dt}(U) = Q'$$

where,

U = Internal energy of the pressurizer assembly, Btu

Q' = Heat loss rate, Btu/hr

The heat loss rate Q' is made up from the following components:

$$Q' = q_i'' A_i + q_s' P_s + Q_m'$$

where,

q_i'' = heat loss per unit area of the insulated portion - excluding the skirt (Btu/hr-ft²)

A_i = Area corresponding to q_i'' (ft²)

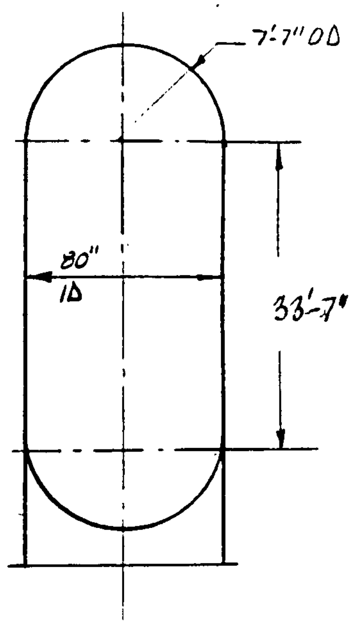
q_s' = heat loss per unit length of the skirt, (Btu/hr-ft)

P_s = perimeter of the skirt, (ft)

Q_m' = miscellaneous heat losses, Btu/hr

These components are determined on the following pages

Pressurizer Dimensions / parameters (Ref. 7, 19)



Total volume : $1300\ ft^3$

Water Vol. : $630\ ft^3$ **

Material : Steel

$k = 31\ Btu/hr\text{-}ft\text{-}°F$

$\rho = 490\ lb/ft^3$

$c = 0.11\ Btu/lb\text{-}°F$

Insulation : 4" Glass wool ($1.5\ lb/ft^3$)

(See p. 20 for k)

Conditions : $P = 2100$ psia *

$T = 643°F$

Thickness (Ref. 7) :

Beltline	= 5-7/16"	(5.45")
Upper head	= 3-1/4"	(3.25")
Lower head	= 2-5/8"	(2.6")

---

* At $P = 2100$ psia

$T = 643°F$

$\rho_f = 38.2\ lb/ft^3$ $h_f = 684\ Btu/lb$

$\rho_g = 5.7\ lb/ft^3$ $h_g = 1131\ Btu/lb$

** According to Reference 11,

Water Volume at Minimum Level $= 230\ ft^3$

Water Volume at Nominal Level $= 630\ ft^3$

Water Volume at High Al. level $= 670\ ft^3$

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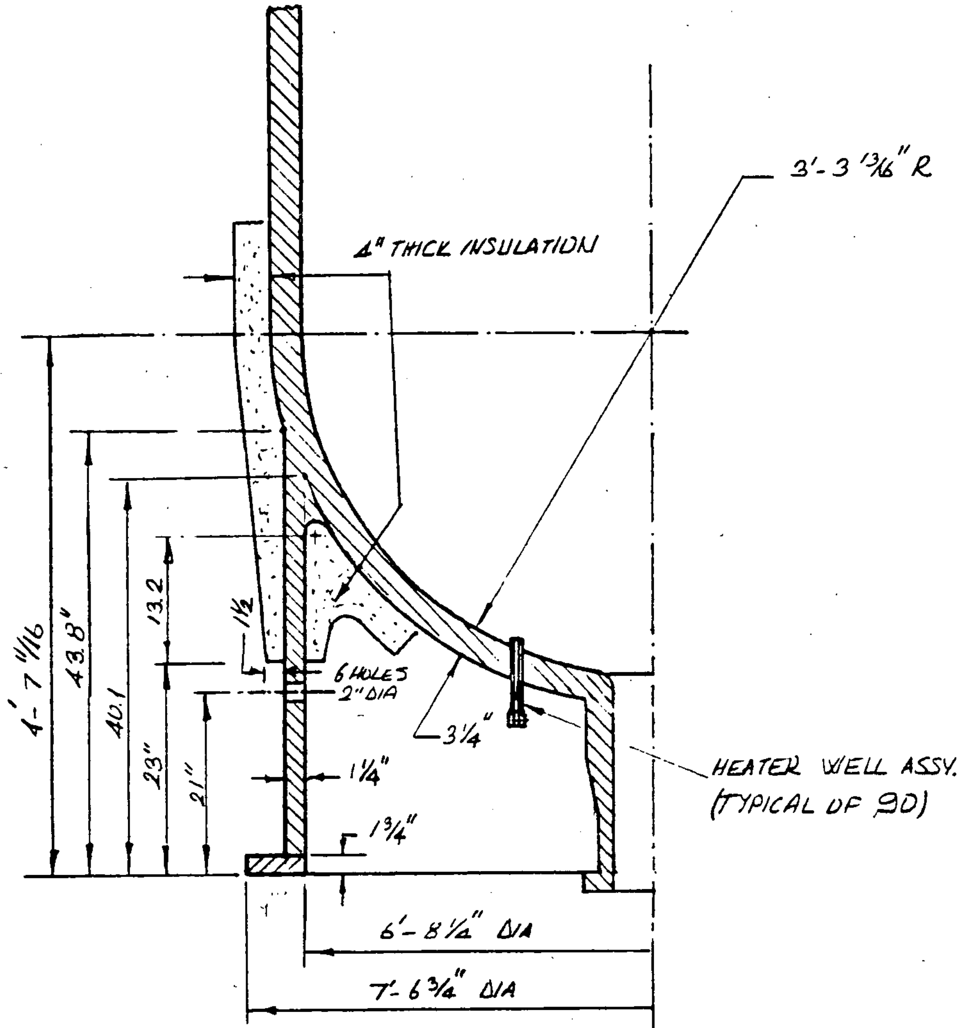
Source: Ref. 10



Pressurizer Skirt and Insulation Details

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Skirt Length

$$X^2+Y^2 = \left(3\times12+3+\frac{13}{16}+3+\frac{1}{4}\right)^2 = 43.06^2$$

$$x = \frac{1}{2}\left(6\times12+8+\frac{1}{4}\right) = 40.13$$

$$Y = \left(43.06^2 - 40.13^2\right)^{1/2}$$

$$= 15.6 \text{ in}$$

$$l = 4\times12+7+11/16 - 15.6$$

$$= 40.1 \text{ in}$$

length from the 7/8" fillet

$$x = \frac{1}{2}\left(6\times12+8+\frac{1}{4}\right) - 2\times 7/8$$

$$= 38.4 \text{ in}$$

$$Y = \left(43.06^2 - 38.4^2\right)^{1/2}$$

$$= 19.5 \text{ in}$$

$$l = 4\times12+7+11/16 - 19.5$$

$$= 36.2 \text{ in}$$

Insulated length = 13.2 in

Uninsulated length = 27 in

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Insulation Material (Source : Ref. 20)

Material : Owens/Corning Fiberglass (Insul-Quick)
Thermal Conductivity, k

Temp. (°F)	k Btu/hr-ft-°F	k^* (2nd order)	k^* (1st order)
100	.021	.021	.017
200	.026	.026	.026
300	.033	.033	.035
400	.040	.041	.044
500	.052	.051	.053
600		.064	.062
650		.070	.067

* calculated using a second order polynomial fit to the data under column 2.

$k = 8.93 \times 10^{-8} T^2 + 2.23 \times 10^{-5} T + 0.018$ (2nd order

$k = 8.21 \times 10^{-3} + 9.04 \times 10^{-5} T$ (1st order)

Heat Loss Through 4" Insulation, q:

Heat losses through the insulation have been calculated based on the following assumptions:

1. Pressurizer wall temperature is the same as the pressurizer bulk fluid temperature.
2. The outside film coefficient (including the radiation effects) is 1. Btu/hr-ft²-°F.
3. Heat transfer through the insulation can be approximated as a quasi-steady process.

Based on these,

$$\frac{d}{dx}\left(k\,\frac{dT}{dx}\right) = 0. \qquad (1)$$

using,

$k = aT + b$ (with $a = 9.04 \times 10^{-5}$, $b = 8.21 \times 10^{-3}$ on p: 20)

$$\frac{a}{2}T^2 + bT = cx + d$$

Using the boundary conditions

$$x = 0, \quad T = T_0$$
$$x = t, \quad k\frac{dT}{dx} = -h\,(T - T_\infty)$$

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from the first boundary condition

$$d = \frac{a}{2} T_o^2 + b T_o$$

from the second,

$$c = -h(T_s - T_\infty)$$

substituting back,

$$\frac{a}{2} T^2 + bT = -h(T_s - T_\infty)x + \frac{a}{2} T_o^2 + b T_o \qquad (2)$$

since,

$$T = T_s \quad at \quad x = t$$

$$\frac{a}{2} T_s^2 + b T_s = -h(T_s - T_\infty)t + \frac{a}{2} T_o^2 + b T_o$$

or

$$T_s^2 + \left(\frac{2b}{a} + \frac{2ht}{a}\right) T_s - \left(\frac{2ht T_\infty}{a} + T_o^2 + \frac{2bT_o}{a}\right)$$

which yields,

$$T_s = -\left(\frac{b}{a} + \frac{ht}{a}\right) + \sqrt{\left(\frac{b}{a} + \frac{ht}{a}\right)^2 + \left(\frac{2htT_\infty}{a} + T_o^2 + \frac{2bT_o}{a}\right)} \qquad (3)$$

and the heat loss is given by

$$q'' = h(T_s - T_\infty) \qquad (4)$$

Validity of equations (3) and (4) are checked against Reference 20 Table on p:20. Following is comparison of this check

Ambient temperature, $T_\infty = 80°F$
Insulation thickness, $t = 4$ inches
film coefficient, $h = 1$ Btu/hr-ft²-°F
$a = 9.04 \times 10^{-5}$ Btu/hr-ft
$b = 8.21 \times 10^{-3}$ Btu/hr-ft-°F

Operating Temperature (Deg. F)	Heat Flux, q'' (Btu/hr-ft²-°F) Ref. 20	Equations 3&4
300	16	16
350	21	21.3
400	26	27.3
450	32	34
500	39	41.2
550	47	49.1
600	56	57.6
650	65	66.8

The maximum deviation is six percent.

Equations (3) and (4) when applied to the conditions of the pressurizer ($T_\infty = 120°F$) yield:

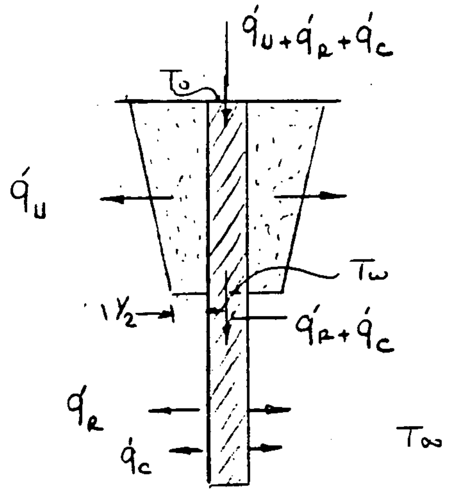
Operating Temp. (Deg. F)	Heat Flux, q_i'' (Btu/hr.ft²) 2" Insul.	3" Insul.	4" Insul.
150	3.3	2.3	1.7
200	9.7	6.7	5.2
250	17.4	12.	9.2
300	26.2	18.1	13.9
350	36.2	25.1	19.2
400	47.3	32.8	25.1
450	59.5	41.4	31.7
500	72.8	50.7	38.9
550	87.3	60.9	46.7
600	102.8	71.8	55.1
650	119.3	83.6	64.2

Heat Losses Through the Skirt, q'_o

The skirt is considered as a rectangular fin of uniform crossection composed of two parts:

1. Insulated upper section
2. Uninsulated lower section

The system configuration is illustrated below



Upper Portion

The upper portion disippates heat laterally through the insulation. It also conducts axially providing a heat flow path for the uninsulated lower portion. The conduction mode will be considered in conjunction with the lower portion.

The convection losses can be estimated by ~~assuming~~ using a linear temperature profile and a linearly varying insulation thickness. Since in reality the temperature along the skirt varies exponentially this assumption results in overestimation of the heat losses.

$$q'_{cv} = \int_0^{l} U \cdot (T - T_\infty)\, dx$$

$$U = \left(\frac{1}{h} + \frac{t_i}{k_i}\right)^{-1}$$

where,

$h = 1$ Btu/hr-ft²-°F

$k_i = 0.067 \times 12$ Btu-in/hr-ft²-°F

$t_i = 4 - \frac{4-1.5}{20.8}(x + 6.8)$ (from Fig. on P:18)

$= 3.2 - 0.12x$

Therefore,

$$U = \left(1 + \frac{3.2 - 0.12x}{12 \times 0.067}\right)^{-1}$$

$$= (5 - 0.15x)^{-1}$$

Similarly,

$$T - T_\infty = T_0 - \frac{T_0 - T_w}{(14/12)}x - T_\infty$$

$$= (T_0 - T_\infty) - \frac{12}{14} \cdot (T_0 - T_w) \cdot x$$

$$= (T_0 - T_\infty) - 0.86\,(T_0 - T_w)\,x$$

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Substituting into the integral,

$$q_u' = \int_0^{14/12} \left[\frac{T_0 - T_\infty}{5-0.15x} - 0.86\,(T_0 - T_w) \cdot \frac{x}{5-0.15x} \right] dx$$

$$= (T_0 - T_\infty)\left[\frac{1}{-0.15}\ln(5-0.15x)\right]_0^{14/12} - 0.86\,(T_w - T_\infty)\left[\frac{x}{-0.15} - \frac{5}{0.15^2}\ln(5-0.15x)\right]_0^{14/12}$$

$$q_u' = \underline{0.238\,(T_0 - T_\infty) - 0.12\,(T_w - T_\infty)} \quad \text{Btu/hr-ft-°F}$$

Using the values for T_w calculated for the lower portion, q_u' is tabulated in the Table on page 32.

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Lower Portion (uninsulated)

The uninsulated lower portion dissipates heat to the surrounding by radiation and convection. By considering the skirt as a rectangular fin with uniform crossection, and by defining an equivalent surface heat transfer coefficient this problem can be solved as a standard convective fin problem. The equivalent heat transfer coefficient is determined as follows:

$$h_e (T-T_\infty) = h (T-T_\infty) + \sigma \epsilon (T^4 - T_\infty^4)$$

$$= h (T-T_\infty) + \sigma \epsilon (T-T_\infty)(T^3 + T^2 T_\infty + T T_\infty^2 + T_\infty^3)$$

$$h_e = h + \sigma \epsilon (T^3 + T^2 T_\infty + T T_\infty^2 + T_\infty^3)$$

with,

$h = 1$ Btu/hr-ft^2-°F

$\sigma = 0.1714 \times 10^{-8}$ Btu/hr-ft^2-°R^4 , $\epsilon = 0.9$

$T_\infty = 120 + 460 = 580$°R

and

$(120+460) \leq T \leq (653+460)$

The maximum and minimum values of h_e are:

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$h_e(max) = 5.1$ Btu/hr-ft²-°F

$h_e(min) = 2.2$ Btu/hr-ft²-°F

The heat loss per unit length of the skirt is given by (Reference 18 p: 3-113)

$$q'_l = \sqrt{h_e k \delta}\left[2(\tanh ml + \sqrt{Bi})/(\sqrt{Bi}\tanh ml + 1)\right](T_w - T_\infty)$$

where,

δ = half thickness, $1.25/_{2 \times 12}$ ft

$m = (h/_{k\delta})^{1/2}$

$B_i = h\delta/_k$

l = length, $27/_{12} = 2.29$ ft

For the range of h_e considered, the expression inside the bracket varies from 2.0 to 1.9. To simplify the mathematics, therefore, q' can be conservatively taken as:

$$q'_l = 2\sqrt{h_e k \delta}\ (T_w - T_\infty) \checkmark$$

The equivalent heat transfer coefficient, h_e,

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will be evaluated at the fin base temperature T_w. This will result in overestimation of the heat losses.

In solving the heat dissipation, q', it must be realized that it is transferred through the insulated upper portion in axial conduction mode. Therefore

$$q'_l = (2\delta \times 1) \cdot \frac{T_o - T_w}{l} \cdot k$$

$$= (1.25/12) \times \frac{T_o - T_w}{(13.2/12)} \times 31$$

$$= 2.94\,(T_o - T_w)$$

or,

$$T_w = T_o - q'/2.94$$

Summary:

The heat loss from the lower (uninsulated) portion of the skirt is determined from the following equations:

$$q'_l = 2\sqrt{h_e k \delta}\,(T_w - T_\infty) \quad , \quad k = 31\ \text{Btu/hr-ft-°F}$$

$$h_e = h + \sigma\epsilon\,(T_w^3 + T_w^2 T_\infty + T_w T_\infty^2 + T_\infty^3)$$

$$T_w = T_o - q'_l/2.94$$

With the known parameters defined before, the solution is given below

T_o - 460 (°F)	T_w - 460 (°F)	h_e (Btu/hr-ft²-°F)	q'_l (Btu/hr-ft)	q'_u (Btu/hr-ft)	$q'_u + q'_l$ (q'_o)
650	332	3.04	939	101	1040
600	313	2.95	842	91	933
550	295	2.87	753	81	834
500	275	2.78	657	72	729
450	256	2.70	568	62	630
400	237	2.62	481	53	534
350	217	2.54	393	43	436
300	196	2.46	303	34	337
250	176	2.39	220	24	244
200	155	2.32	135	15	150
150	133	2.25	50	6	56

Miscellaneous Heat Losses, $\dot{Q}_m$

In addition to the losses through the 4" insulation and skirt, there are losses through various attachments to the pressurizer. These attachments are:

- pipes
- Lugs
- Heater wells

At this stage the full geometrical and insulation details about these components are not known. The miscellaneous heat losses, $\dot{Q}_m$, therefore has been approximated using the information provided in Reference 21 . This reference states that at the normal operating conditions heat losses through the lugs amount to 10700 Btu/hr. It is assumed that this value represents the miscellaneous heat losses at the normal pressurizer temperature of 653°F. At lower temperatures a convective relation has been assumed which maximizes the total heat losses. Thus,

$$\dot{Q}_m = 10700 \times \frac{T_o - 120}{653 - 120}$$

where T_o is the pressurizer temperature

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Total Heat Loss, Q'

The total heat loss from the pressurizer is obtained by summing up the individual heat losses determined in the previous sections

$$Q' = q_i'' A_i + q_s' \pi D_s + Q_m'$$

where,

D_s = skirt diameter (6.9 ft)

A_i = insulated area excluding the skirt

$= \pi D^2 + \pi D h$

$= \pi \times 7.6^2 + \pi \times 7.6 \times 34.4$

$= 1003 \ ft^2$

$q_i'' =$ (p: 24)

$q_s' =$ (p: 32)

$Q_m' =$ (p: 33)

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Temp. (°F)	q_i'' Btu/hr-ft²	q_o' Btu/hr-ft	Q_m' Btu/hr	Q' Btu/hr
650	64.2	1040	10700	97636
600	55.1	933	9691	85180
550	46.7	834	8681	73600
500	38.9	729	7672	62500
450	31.7	630	6662	52100
400	25.1	534	5653	42400
350	19.2	436	4643	33350
300	13.9	337	3634	24880
250	9.2	244	2625	17140
200	5.2	150	1615	10082
150	1.7	56	606	3525

$Q' = 0.132\,T^2 + 82.27\,T - 11612$

or $Q' = 187.2\,T - 24393$

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Pressurizer Heat Capacity

$$U = M_f u_f + M_g u_g + M_s u_s$$

where

M = mass, lb_m
u = internal energy, Btu/lb_m
f = saturated water
g = saturated steam
s = steel

Heat capacity of attachments and insulation material has been ignored.

Assuming constant pressurizer inventory at normal operating conditions (630 ft³ water, 670 ft³ steam) (saturated)

$$M_f = M_o - M_g$$
$$= M_o - \frac{V_g}{v_g}$$

where,

M_o = initial water inventory, lb_m
V_g = pressurizer steam volume (670 ft³), taken constant
v_g = saturated steam specific volume.

Thus,

$$U = \left(M_o - \frac{V_g}{v_g}\right) u_f + \frac{V_g}{v_g} u_g + M_s c_s (T - 32)$$

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Rearranging,

$$U = M_o \left[u_f + \frac{V_g}{M_o v_g} (u_g - u_f) + \frac{M_s}{M_o} c_s (T-32) \right]$$

with $\quad M_o = \frac{V_g}{v_{go}} + \frac{V_f}{v_{fo}}$

$$\frac{V_g}{M_o v_g} = \frac{V_g}{\left(\frac{V_g}{v_{go}} + \frac{V_f}{v_{fo}}\right) v_g} = \frac{1}{1 + \frac{V_f}{V_g} \cdot \frac{v_{go}}{v_{fo}}} \cdot \frac{v_{go}}{v_g}$$

Therefore,

$$U = M_o \left[u_f + \frac{1}{1 + \frac{V_f}{V_g} \cdot \frac{v_{go}}{v_{fo}}} \cdot \left(\frac{v_{go}}{v_g}\right) (u_g - u_f) + \frac{M_s c_s}{M_o} (T-32) \right]$$

with

$V_f = 630\ ft^3$

$V_g = 670\ ft^3$

$v_{fo} = 0.02618\ ft^3/lbm$ $\quad$ {at 643°F}

$v_{go} = 0.17456\ ft^3/lb$

$$U = M_o \left[u_f + 0.138 \left(\frac{v_{go}}{v_g}\right)(u_g - u_f) \right] + M_s c_s (T-32)$$

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$$U = M_o \left[u_f + 0.138 \frac{v_{go}}{v_g} (u_g - u_f) + \frac{M_s}{M_o} c_s (T-32) \right]$$

Taking $T_{ref} = 32°F$ the temperature dependent terms of this equation are tabulated below:

T (°F)	v_g	u_f (Btu/lbm)	u_g	$u_f + 0.138 \frac{v_{go}}{v_g} (u_g - u_f) = X$ (Btu/lbm)
650	0.16173	685.5	1052.8	740.2
600	0.2677	609.9	1090.	653.1
550	0.4268	545	1108.4	576.8
500	0.6761	485.1	1117.4	507.6
450	1.1011	428.6	1119.5	443.7
400	1.8661	374.27	1116.6	383.0
350	3.346	321.35	1109.8	327.
300	6.472	269.5	1100.	272.6
250	13.826	218.5	1087.9	220.
200	33.63	168.	1074.2	168.6
150	97.	118.	1059.3	118.2

$v_o = 0.0268\ ft^3/lb$

$X = 7.24 \times 10^{-4} T^2 + 0.64T + 11.16$

or $X = 1.219T - 86.56$

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Pressurizer Heat Balance

$$-\frac{dU}{dt} = \dot{Q}$$

$$U = M_o(7.24\times10^{-4}T^2 + 0.64T + 11.16) + M_s C_s (T-32)$$

$$Q' = 0.132T^2 + 82.3T - 11612$$

$$-\frac{dU}{dt} = \left[M_o(1.45\times10^{-3}T + 0.64) + M_s C_s\right]\frac{dT}{dt}$$

with,

$M_o = 27885$ lb $(630 \times 38.2 + (1300-630) \times 5.7)$

$M_s = 205000$ lb *

$C_s = 0.11$ Btu/lb-°F

$$\frac{dU}{dt} = (40.4T + 40400)\frac{dT}{dt}$$

Therefore

$$-t = \int_{643}^{T} \frac{40.4T + 40400}{0.132T^2 + 82.3T - 11612}\, dT$$ ✓

---

* Per Ref 19 Dry weight = 210000 lb. 5000 lb has been allowed for the skirt, nozzles and lugs

$$\int \frac{ax+b}{Ax^2+Bx+C}\,dx$$

$$= a\left[\frac{1}{2A}\ln(Ax^2+Bx+C) - \frac{B}{2A}\left(\frac{1}{\sqrt{B^2-4AC}}\ln\frac{2Ax+B-\sqrt{B^2-4AC}}{2Ax+B+\sqrt{B^2-4AC}}\right)\right]$$

$$+ b\left[\frac{1}{\sqrt{B^2-4AC}}\ln\frac{2Ax+B-\sqrt{B^2-4AC}}{2Ax+B+\sqrt{B^2-4AC}}\right] + K$$

$$= \frac{a}{2A}\ln(Ax^2+Bx+C) + \left(b-\frac{aB}{2A}\right)\frac{1}{\sqrt{B^2-4AC}}\ln\frac{2Ax+B-\sqrt{B^2-4AC}}{2Ax+B+\sqrt{B^2-4AC}} + K$$

with,

$a = 40.4$

$b = 40400$

$A = 0.132$

$B = 82.3$

$C = -11612$

and $T = 643°F$ @ $t = 0$.

$\sqrt{B^2-4AC} = 113.6$

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Therefore

$$t = \left[\frac{40.4}{2 \times 0.132} \ln (0.132T^2 + 82.3T - 11612) + \left(40400 - \frac{40.4 \times 82.3}{2 \times 0.132}\right) \frac{1}{113.6} \ln \frac{2 \times 0.132T + 82.3 - 113.6}{2 \times 0.132T + 82.3 + 113.6} \right]_T^{643}$$

$$t = 1517.3 - \left[153 \ln (0.132T^2 + 82.3T - 11612) + 244.8 \ln \frac{0.264T - 31.3}{0.264T + 195.9} \right]$$

solution is tabulated on the next page

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Time (hr)	Press. Temp. (Deg. F)	T_v (P_v) (Deg. F)		Press. Pressure (psia)
0	643	643	(2100)	2100
2.1	640	620	(1900)	2060
5.6	635	620	(1900)	1980
9.2	630	583	(1337)	1919
12.7	625	567	(1200)	1852
16.3	620	567	(1200)	1787
23.6	610	567	(1200)	1662
31	600	562	(1152)	1543
51	575	462	(476)	1275
71	550	362	(157)	1045
93	525	252	(31)	848
117	500			681
169	450			423
231	400			247
304	350			134
396	300			67
520	250			30
706	200			
1080	150			

T_v, (P_v): Minimum Allowable pressurizer temperature (pressure) to prevent voiding (pp: 12, 13, 14)

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CALC NO TH-[illegible]

3.5 Reactor Coolant Shrinkage

Cooldown of the reactor coolant system is accompanied by shrinkage of the coolant. In order to maintain the desired pressurizer level and avoid voiding of the primary system components make-up flow must be available at a rate to compensate for the shrinkage. In theory, additional factors, such as the pressurization and contraction of the primary system boundaries provide some compensation for the shrinkage. These effects, however, are small in magnitude and have been neglected in this calculation.

Therefore,

$V = M v$

where

V = Reactor coolant volume

M = Reactor coolant mass

v = Specific volume of the coolant.

Shrinkage effects are tabulated on the following page.

Temperature (°F) /Hr ***	Spec. Vol. (ft³/lb)	Percent Change (*)	Volume Change (ft³) / Gal. **
550	.02176	0.	0.
500 / 4	.02043	-6.1	-398 / 3000
450 / 6	.01944	-10.7	-698 / 5200
400 / 8	.01864	-14.3	-933 / 2000
350 / 10.30	.01799	-17.3	-1129 / 8400
300 / 40	.01745	-19.8	-1292 / 9700
250 / 50	.017006	-21.9	-1430 / 10700
200 / 60	.016637	-23.5	-1534 / 11500
150	.016343	-25.	-1632 / 12200

* Referenced to 550°F average vessel temperature

** $\Delta V = M \cdot \Delta v$

$= V * \text{Percent change}$

$M = 3 \times 10^5$ lb (Ref. 3, page 17)

$V = M \times v = 3 \times 10^5 \times 0.02176$

$= 6528\ ft^3$

*** The time values correspond to the cooldown curve to prevent void formation (Section 3.3)

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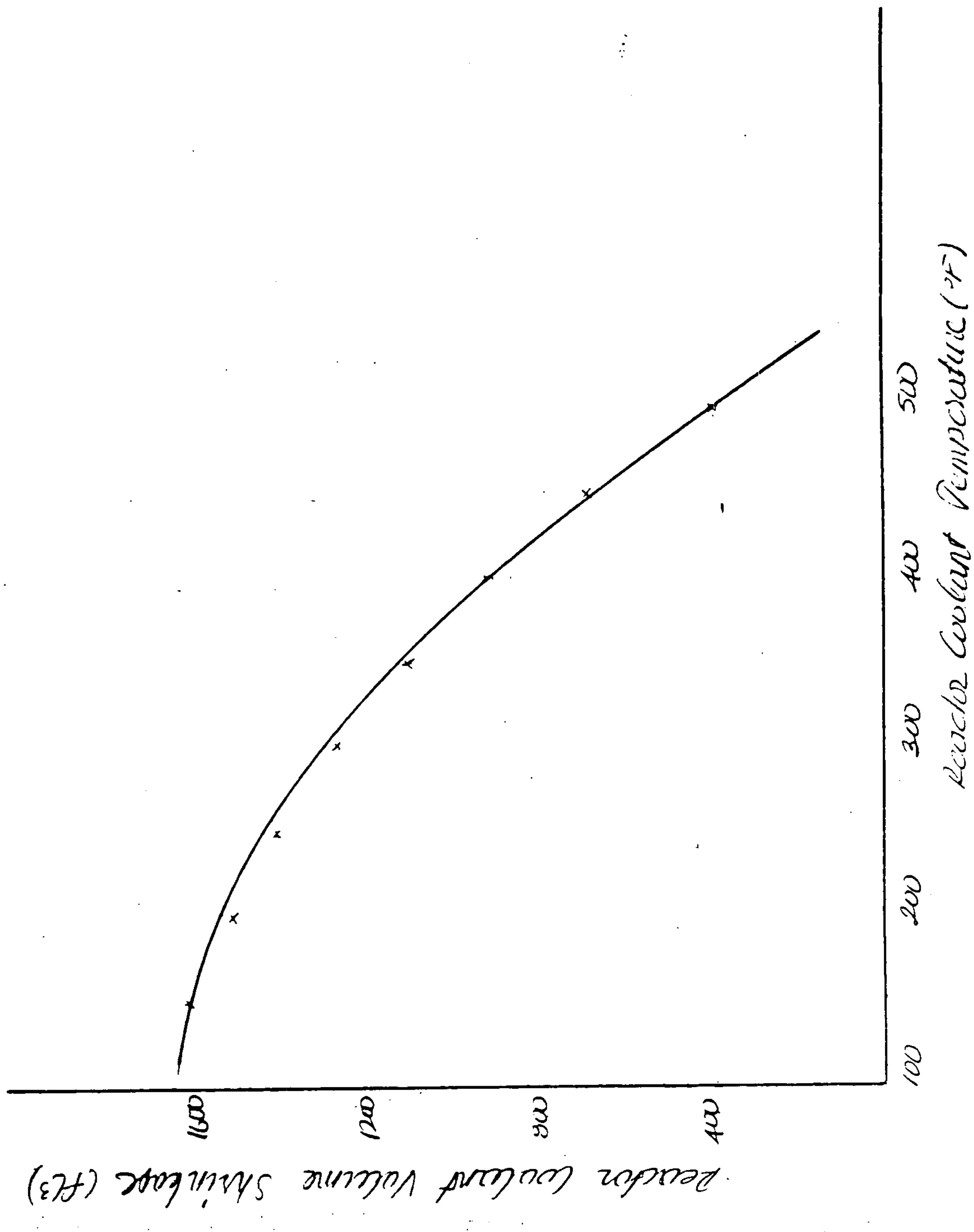

FIGURE 3.5 - REACTOR COOLANT VOLUME SHRINKAGE

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3.6 Natural Circulation

Natural circulation is essential to the removal of the decay heat and the stored heat from the primary system. It is established and maintained by providing an appropriate temperature difference between the reactor and the steam generator. This temperature difference creates the necessary buoyancy force for the natural circulation.

The equation describing the natural circulation can be obtained by:

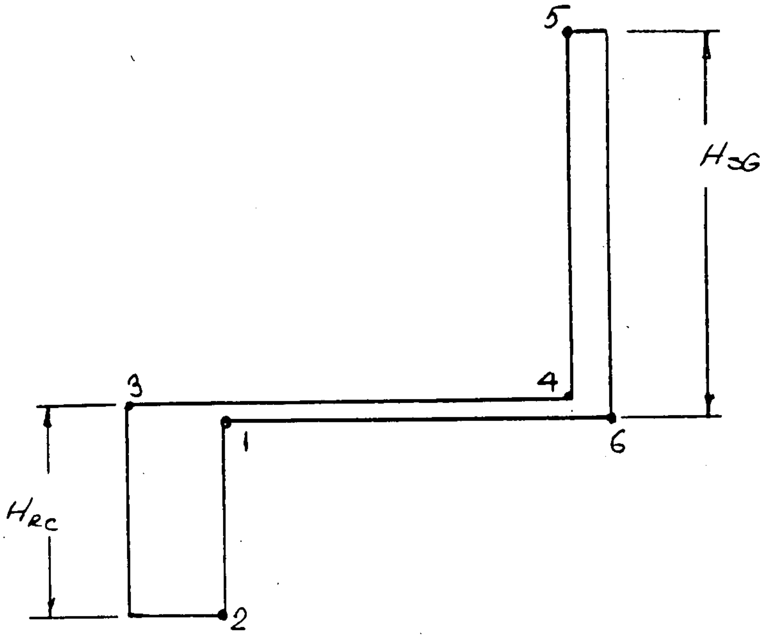
1. Momentum equation,

$$\oint \rho g \, dz = \frac{1}{2} \rho R Q^2$$

where,

ρ = density
g = gravitational acceleration
z = vertical coordinate
Q = volumetric flow rate
R = overall loop flow resistance

Integrating the left side of this equation with the help of the sketch on the following page,



SEGMENT	AVERAGE DENSITY	GRAVITY HEAD
1-2	ρ_C	$+\rho_C \cdot H_{RC}$
2-3	$\frac{1}{2}(\rho_C+\rho_H)$	$-\frac{1}{2}(\rho_C+\rho_H)\ H_{RC}$
4-5	$\frac{1}{4}(3\rho_H+\rho_C)$	$-\frac{1}{4}(3\rho_H+\rho_C)\ H_{SG}$
5-6	$\frac{1}{4}(3\rho_C+\rho_H)$	$+\frac{1}{4}(3\rho_C+\rho_H)\ H_{SG}$

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CALC NO 7.1.1

$$\text{Total Head} = H_{RC}\left(\rho_C - \tfrac{1}{2}\rho_C - \tfrac{1}{2}\rho_H\right) g$$

$$+ \frac{H_{SG}}{4}\left(3\rho_C + \rho_H - 3\rho_H - \rho_C\right) g$$

$$= \frac{H_{RC}}{2}\left(\rho_C - \rho_H\right) + \frac{H_{SG}}{4}\left(2\rho_C - 2\rho_H\right) g$$

$$= \left(\rho_C - \rho_H\right)\left(\frac{H_{RC} + H_{SG}}{2}\right) g$$

$$H_B = \Delta\rho \cdot H_{EQ} \cdot g$$

where,

H_B = Buoyancy head

H_{EQ} = equivalent elevation difference

$= \frac{1}{2}\left(H_{RC} + H_{SG}\right)$

$\Delta\rho = \rho_C - \rho_H$

The density difference, $\rho_C - \rho_H$, can be related to the corresponding cold leg and hot leg temperature through the thermal expansion coefficient β, as

$$\Delta\rho = \rho\beta\,\Delta T$$

$$\Delta\rho = \rho_C \cdot \beta\left(T_H - T_C\right)$$

yielding

$$H_B = \beta \cdot \rho_C\left(T_H - T_C\right) H_{EQ} \cdot g$$

The core energy balance gives

$$Q \cdot \rho_c \cdot C \cdot (T_H - T_c) = q'$$

where,

q' = decay heat rate
c = specific heat
Q = volumetric flow

Combining this equation with the previous

$$H_B = \frac{\beta q'}{Q c}$$

And finally substituting this into the momentum equation

$$\frac{\beta q'}{Q c} = \frac{1}{2} \rho_c R Q^2$$

Solving for Q

$$Q = \left(2 \beta g \, H_{EQ} \, q' / \rho_c c R\right)^{1/3}$$

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Summary:

The natural circulation rate is given by

$$Q = \left(\frac{2 \beta g H_{EQ} \, q'}{\rho C R}\right)^{1/3}$$

where

Q = volumetric flow rate, ft^3/sec

β = Thermal expansion coefficient, $°F^{-1}$

g = gravitational acceleration, 32.2 ft/sec^2

H_{EQ} = Equivalent elevation difference

$= \frac{1}{2}(H_{RC} + H_{SG})$

q' = Decay heat rate, Btu/sec (per steam generator)

ρ = Cold leg density, lb/ft^3

C = specific heat, Btu/lb-°F

R = Resistance Coefficient $\left(\sum \frac{k_i}{A_i^2}\right)$, ft^{-4}

The thermal expansion coefficient for water is a function of temperature. This variation is shown on the following page

Temp. (°F)	β (°F^{-1})	ρ (lb/ft^3)	c (Btu/lb-°F)
100	2×10^{-4}	62	1.
200	4×10^{-4}	60.1	1.
300	5.7×10^{-4}	57.3	1
400	7.8×10^{-4}	53.7	1.
500	11.2×10^{-4}	49.	1.2
600	19.6×10^{-4}	42.3	1.4

$H_{ec} + H_{sb} \simeq 50 ft$ (from Fig. 2.1 of Ref. 7)

Using the values at the median temperature of 300°F,

$$\beta = 5.7\times10^{-4}$$
$$\rho = 57.3 \ lb/ft^3$$
$$c = 1. \ Btu/lb\text{-}°F$$

and noting that,

$$q' = (DH/3)/3600$$
$$R = 0.54 \ ft^{-4}$$ (calculated on page 34)

$$Q = \left[2\times 5.7\times10^{-4}\times 32.2\times 50/2\times DH/(3\times3600)\Big/57.3\times 1.\times 0.54\right]^{1/3}$$

$$= 0.014\,(\Delta H)^{1/3} \quad ft^3/sec$$

where,

DH = Decay Heat (Btu/hr) as given on page 9)

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Noting that this flow rate is per loop and that, there are three loops the core flow rate is,

$$\dot{m} = 3 \rho Q \times 3600$$

$$= 3 \times 0.014 (\Delta H)^{1/3} \times 57.3 \times 3600$$

$$= 8.7 \times 10^3 (\Delta H)^{1/3} \quad lb/hr.$$

The corresponding temperature differential is,

$$\Delta T = T_H - T_C = \Delta H / \dot{m} C$$

$$= 1.2 \times 10^{-4} (\Delta H)^{2/3}$$

$$\dot{m} = 8.7 \times 10^3 (\Delta H)^{1/3}$$

$$\Delta T = 1.2 \times 10^{-4} (\Delta H)^{2/3}$$

Values of core flow rate, $\dot{m}$, and temperature difference, ΔT, are calculated on the following page.

Time (Hr.)	Decay Heat (10^6 Btu/hr)		Core Flow (10^3 lb/hr)		ΔT (°F)
1/6	248	(5.4)	5375	(6.9)	48
1	73	(1.6)	3580	(4.6)	21
2	58.5	(1.3)	3320	(4.3)	18
4	48.2	(1.1)	3110	(4.)	16
5	45.4	(1.)	3050	(3.9)	15.3
10	37.9	(.8)	2880	(3.7)	13.5
25	29.1	(.6)	2630	(3.4)	11.4
32	27.1	(.6)	2570	(3.3)	10.8
50	23.5	(.5)	2450	(3.1)	9.8
100	18.5	(.4)	~~2560~~ 2260	(2.9)	8.4 △
150	15.7	(.3)	2140	(2.7)	7.5

Numbers in parenthesis represent the percentages based on 100% Load Core Thermal Power (1340 Mwt) and Core Flow Rate (78×10^6 lb/hr)

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Resistance Coefficient

The turbulent resistance coefficient, R, is estimated from the primary system design data as,

$$\Delta P = R \frac{1}{2 \times 144 g_c} \frac{\dot{m}^2}{\rho} \times \left(\frac{1}{3600}\right)^2$$

where,

ρ = Coolant density, 47. lb/ft³ (At T_c = 553°F)
$\dot{m}$ = Steam Generator flow Rate, 26×10^6 lb/hr
ΔP = Reactor coolant pump head, 65 psi

Therefore,

$$R = 2 \times 65 \times 144 \times 32.2 \times 47 \Big/ \left(26 \times 10^6 / 3600\right)^2$$

$$R = 0.54 \ ft^{-4}$$

<u>NOTE</u>: At 100% power the flow is fully turbulent with,

$$Re = 123.9 \frac{\rho v d}{\mu}$$

where,

ρ = 47 lb/ft³
v = 87 ft/sec (Based on 26×10^6 lb/hr, flow and 18" pipe diameter)
d = 18"
μ = 0.111 cp

$Re = 8 \times 10^5 \gg 2300$ (Critical Reynolds number)

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At 200°F, $\mu = 0.313$ and with core flow reduced to 1 percent of the value at full power,

$$Re = 8\times10^5 \times 0.01 \times \frac{0.111}{0.313} = 2900$$

still greater than the critical Reynolds number (2300) for pipe flow. Therefore the assumption of turbulent flow during the shutdown with natural circulation is valid.

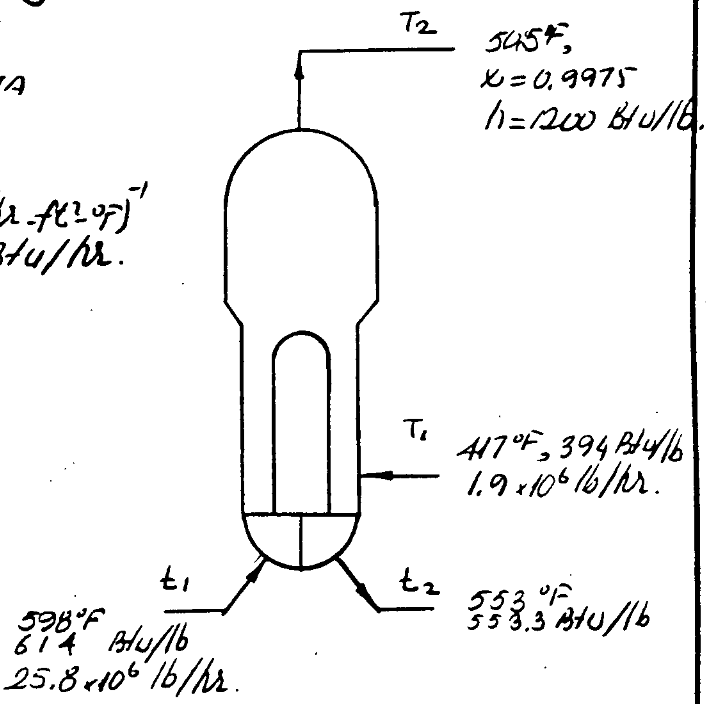
3.7 Steam Generator Capacity

STEAM GENERATOR DATA
(Source: Reference 15)

Heating Surface $= 27700\ ft^2$
Fouling Factor $= .0002\ (Btu/hr\text{-}ft^2\text{-}°F)^{-1}$
Heat Transferred $= 1532 \times 10^6\ Btu/hr.$

Operational Limitations:

- 50°F step change on the steam side
- ∓ 100°F/hr on the primary (tube) side



U-tubes:

$n = 3794$
$t = 0.055\ in$
$OD = 0.75\ in$

<u>NiCrFe alloy</u>

$k = 11\ Btu/hr\text{-}ft\text{-}°F$

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Overall Heat Transfer Coefficient - Normal operation

$Q = UA\,\Delta T_{LM}\,F$

$U = Q / A\,\Delta T_{LM}\,F$

$\Delta T_{LM} = \left[(598-417)-(553-505)\right] / \ln\left(\frac{598-417}{553-505}\right)$

$= \underline{100\,°F}$

$F = 0.95$ (from Ref. 10 for, $P = (598-553)/(598-417) = .25$
$R = (505-417)/(598-553) = 1.96$

Therefore,

$U = 1532\times10^6 / 27700 \times 100 \times 0.95$

$U = \underline{582\ Btu/hr\text{-}ft^2\text{-}°F}$

Overall Heat Transfer Coefficient - Natural Circulation

$$U = \left[\frac{1}{h_o} + \left(r_o + r_i\frac{D_o}{D_i}\right) + \frac{1}{h_i}\cdot\left(\frac{D_o}{D_i}\right) + r_w\right]^{-1}$$

$r_w = \frac{D_o}{24k}\left(\ln\frac{D_o}{D_o-2t}\right)$, $k = 11\ Btu/hr\text{-}ft\text{-}°F$

$= \frac{.75}{24\times11}\ln\frac{.75}{.75-2\times.055}$

$= 4.5\times10^{-4}\ (Btu/hr\text{-}ft^2\text{-}°F)^{-1}$

$r_o + r_i\frac{D_o}{D_i} = 2\times10^{-4}$

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$h_o = 580$ Btu/hr-ft²-°F (Minimum from Ref. 11, p:70)
$h_i = 450$ Btu/hr-ft²-°F (Minimum from Ref. 11, p:70

$$U = \left(\frac{1}{580} + 2\times10^{-4} + 4.5\times10^{-4} + \frac{1}{450} \frac{.75}{.75 - 2\times.055} \right)^{-1}$$

$$= (4.98 \times 10^{-3})^{-1}$$

$$U = 200 \text{ Btu/hr-ft}^2\text{-°F}$$

This value represents the minimum overall heat transfer coefficient at the steam generator for the condition during which it is required to operate. In order to allow uncertainties which are not evaluated in this study (plugged steam generator tubes, tube uncovering, excessive fouling and the approximate nature of the film heat transfer coefficients) the value of "U" is further reduced by a factor of 0.5. Thus,

$$U = 200 \times 0.5$$
$$= 100 \text{ Btu/hr-ft}^2\text{-°F}$$

is used in this calculation

Minimum Capacity of the Steam Generator.

With,

$$\dot{q} = U A \Delta T_{LM} F$$

and,

$$U_{min} = 100 \text{ Btu/hr-ft}^2\text{-}^\circ F$$

$$A = 27700 \text{ ft}^2$$

$$\dot{q}_{min} = 27700 \times 100 \times (\Delta T \cdot F)_{min}$$

The minimum ΔT will occur near the cold shutdown conditions, i.e.,

$$t_1 = 195$$

$$t_2 = 195 - 8 = 187^\circ F$$ ($8^\circ F$ required buoyancy head)

$$T_1 = 80^\circ F$$

$$T_2 = 177 F$$ (10° TTD assumed)

Therefore

$$\Delta T_{LM} = \frac{(195-80) - (187-177)}{\ln (195-80)/(187-177)} = 43^\circ F$$

$$P = (t_2 - t_1)/(T_1 - t_1) = 0.05 \longrightarrow F = 1.$$

$$\dot{q}_{min} = 27700 \times 100 \times 43$$
$$= 119 \times 10^6 \text{ Btu/hr.}$$

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The combined minimum capacity of the steam generators is therefore,

$$\dot{q}_{min} = 3 \times 119 \times 10^6$$
$$= 357 \times 10^6 \text{ Btu/hr.}$$

As can be seen this is well above the decay heat and sensible (stored) heat removal rate which is required to achieve the cold shutdown.

REVISION 1 NOTE

Calculation on page 64G indicated that that the 100 Btu/hr-ft²-°F was overestimated. A more realistic value is 48 Btu/hr-ft²-°F. With,

$U = 55$ Btu/hr-ft²-°F

$A = 27700$ ft²/steam generator

$\Delta T_{LM} = 43°F$

$$\dot{q}_{min} = (55 \times 27700 \times 43)$$
$$= 66 \times 10^6 \text{ Btu/hr}$$

which is still well above the decay plus sensible heat removal rate at cold shutdown (see Fig. 3-6 on page 66)

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3.8 Auxiliary Feedwater Cooling Capacity

$T_1 = 80°F$, $h_1 = 48.$ Btu/lb

$\rho_1 = 62.2$ lb/ft^3

$T_2 = 212°F$, $h_f = 180.2$ Btu/lb

$h_g = 1150.5$ Btu/lb

$\dot{m} = 235 \times (62.2/7.48) \times 60$ *

$= 117250$ lb/hr

Heat Removal Capacity,

A- Steaming Mode

$\dot{q}_{SM} = \dot{m} . \Delta h = 117250 \times (1150.5 - 180.2)$

$= 114. \times 10^6$ Btu/hr.

B- Single Phase (liquid) Mode

$\dot{q}_{LM} = 117250 \times (180.2 - 48.)$

$= 15.5 \times 10^6$ Btu/hr.

---

* Based on 235 gpm Motor Driven Aux. Fw. Pump Capacity

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C. Single Phase Mode - at cold shutdown

Assuming $T_2 = 184\,°F$ (i.e., ~5° TTD)
$h_2 = 152$ Btu/lb.

$$q_{SD} = 117250 \times (152 - 48)$$
$$= 12.2 \times 10^6 \text{ Btu/hr.}$$

These numbers have the following implications

1. At the moment of trip and approximately 12(*) minutes following, the decay heat rate exceeds the cooling capacity of the auxiliary feedwater system by a substantial margin. Although there will be a partial compensation for this by steaming at the steam generators, a temperory increase in the primary system temperature is expected during this early period.

2. At the point of transition from the steaming mode to liquid flooded mode the decay heat rate must have reduced to at least 15×10^6 Btu/hr.

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* See Figure 3-6

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3. At the point of cold shutdown the decay heat rate must have reduced to at least 5×10^6 Btu/hr.

It must be realized that these limits are based on the 235 gpm Nominal Pump Capacity. Considering the fact that during this mode of operation the frictional head loss on the secondary side is much smaller than the design frictional head loss the aux feed pump must be capable of delivering more capacity. Assuming that the pump will be operating against 40 percent less head, page 16-25. of Reference 14;

$$H_{NOMINAL} = 2480 \text{ ft} (\sim 1070 \text{ psi})$$
$$H = 2480 \times (1. - 0.4)$$
$$= 1480 \text{ ft}$$

which yields,

$$Q = 400 \text{ gpm}$$
$$NPSH_R = 18 \text{ ft.}$$

At this point the available NPSH is (from Ref. 12)

$$NPSH_a = 33.9 + 4.21 - 4.21 \times \left(\frac{400}{235}\right)^2 = 25.9 \text{ ft.}$$

Therefore the available NPSH is adequate.

The cooling capacity of the Aux. Feed loop being directly proportional to the Aux. Feed flow rate, the cooling limits given on the previous pages can be revised as:

Heat Removal Cap. in the Steaming Mode,

$$q'_{SM} = 114\times10^6 \times \frac{400}{235}$$

$$= 194\times10^6 \text{ Btu/hr.}$$

Heat Removal Cap. in the Single Phase (liquid) Mode

$$q'_{LM} = 15.5\times10^6 \times \frac{400}{235}$$

$$= 26.4\times10^6 \text{ Btu/hr}$$

Heat Removal Cap. at Cold Shutdown ($T_H = 195°F$)

$$q'_{SD} = 12.2\times10^6 \times \frac{400}{235}$$

$$= 20.8\times10^6 \text{ Btu/hr.}$$

Cooling capacity corresponding to 375 gpm pump flow is calculated on the following pages. △1

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Auxiliary Feedwater Cooling Capacity with 375 GPM Pump Flow

Following the request of SCE the cooling capacity provided by the motor driven auxiliary feedwater pump G-10S is calculated using 375 gpm pump flow. In parallel with this, the cold shutdown condition is based on 200°F average reactor coolant temperature. Calculations are performed using the information available in Revision 0 of this calculation with the exception of the pump flow rate and the cold shutdown limit as noted above. First the steam generator effectiveness is determined so that the coolant exit temperature during the single phase cooling mode could be accurately determined

Steam Generator Effectiveness:

The steam generator effectiveness is calculated assuming that a single steam generator is used to achieve shutdown. Effectiveness of a single steam generator is lower than the effectiveness of all three steam generators working in parallel. The assumption therefore, is conservative.

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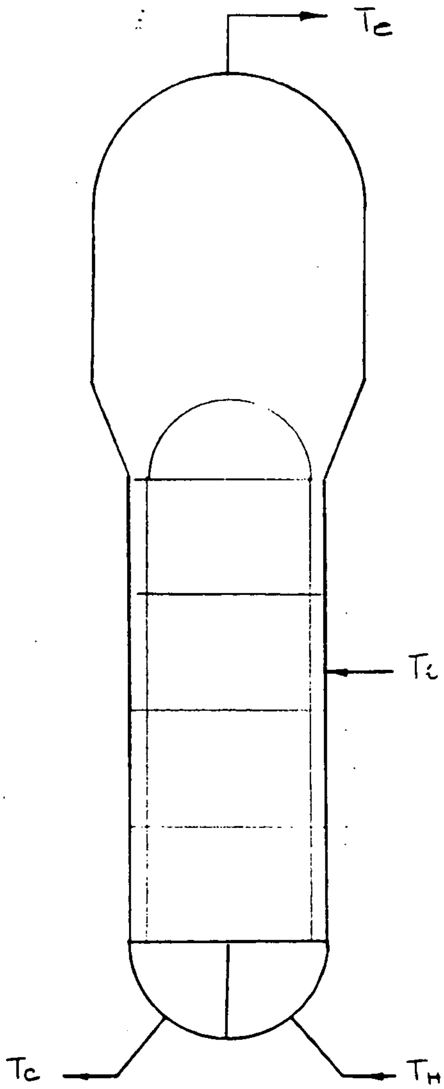
Steam Generator Data (from Ref. 15)

Number of U tubes : 3794
U tube OD : 0.75 in
U tube wall thickn.: 0.055 in

Shell ID : 9 ft (approximate)
Baffle spacing : 3'-9"



Properties of water (from Ref. 22)

Temperature (°F)	c (Btu/lb-°F)	μ (lbf-sec/ft²)	k (Btu/hr-ft-°F)	ν (ft³/lb)
200	1	6.3×10^{-6}	0.39	0.016637
150	1	9.5×10^{-6}	0.38	0.016343

Tube side heat transfer coefficient

$\dot{m} = (2450+2260)\times10^3/2$ (from p: 53 at 75 hr.)

$= 2355\times10^3$ lb/hr

$V = 2355\times10^3 \times 0.016637 \Big/ 3794 \times \pi\left(\frac{0.64}{2\times12}\right)^2 \times 3600$

$= 1.28$ ft/sec

$$Re = \frac{1}{g_c}\cdot\frac{\rho V D}{\mu}$$

$$= \frac{1}{32.2}\cdot\frac{1}{0.016637}\cdot\frac{1.28\times 0.64/12}{6.3\times10^{-6}} \quad \left[\frac{lb_f\text{-}sec^2}{lb_m\text{-}ft}\cdot\frac{lb_m}{ft^3}\cdot\frac{ft}{sec}\cdot ft\cdot\frac{ft^2}{lb_f\text{-}sec}\right]$$

$= 20.2\times10^3 > 2300$

Therefore the flow is turbulent

$$h_i = 0.023\left(\frac{k}{D_i}\right)(Re)^{0.8}(P_r)^{1/3} \qquad (\text{Ref. 23, p: 158})$$

$$P_r = \frac{C_p\,\mu}{k}$$

$$= 1\ \frac{Btu}{lb\cdot{}^\circ F}\times 6.3\times10^{-6}\frac{lb_f\cdot sec}{ft^2}\times\frac{1}{.39}\ \frac{hr\text{-}ft\text{-}{}^\circ F}{Btu}\times 32.2\ \frac{lb_m\text{-}ft}{lb_f\text{-}sec^2}\times 3600\ \frac{sec}{hr}$$

$= 1.87$

$$h_i = 0.023\times\left(\frac{0.39}{0.64/12}\right)\times(20.2\times10^3)^{0.8}\times(1.87)^{1/3}$$

$= \underline{576\ Btu/hr\cdot ft^2\ {}^\circ F}$

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Shell Side Heat Transfer Coefficient

The shell side heat transfer coefficient is calculated using the Kern correlation given in Reference 23 (p.168). The Kern correlation is based on industrial data and has the following form

$$\frac{h_o D_{es}}{k}\left(\frac{C_p \mu}{k}\right)^{-1/3}\left(\frac{\mu}{\mu_w}\right)^{-0.14} = \text{function}\left(\frac{D_{es} \cdot G_s}{\mu}\right)$$

where,

D_{es} = shell side hydraulic diameter

G_s = shell side mass flux

Hydraulic diameter, D_e :

Assuming square pitch arrangement for the pipes,

$$D_{es} = \frac{1}{12}\left\{\frac{4\left(P^2 - \frac{\pi d_o^2}{4}\right)}{\pi d_o}\right\} \quad (\text{Ref. 23 p: 169})$$

The pitch can be estimated by considering the ratio of total tube area to the shell cross-sectional area, i.e.,

$$\frac{\pi d_o^2/4}{P^2} = \frac{2 \times 3794 \times \pi d_o^2/4}{\pi \cdot (9 \times 12)^2/4}$$

$$P^2 = \frac{(\pi/4)\cdot(9 \times 12)^2}{2 \times 3794}$$

$$P = 1.1 \text{ in}$$

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$$D_{es} = \frac{1}{12} \cdot 4\left(1.1^2 - \frac{\pi}{4} \times 0.75^2\right) \Big/ \pi \times 0.75$$

$$= 0.11 \text{ ft} \quad (1.3 \text{ in}) \checkmark$$

A_n (net free area in the tube bundle):

$$A_n = \pi \frac{9^2}{4} - 2 \times 3794 \times \frac{\pi}{4}\left(\frac{0.75}{12}\right)^2$$

$$= 63.6 - 23.3$$

$$= 40.3 \text{ ft}^2 \checkmark$$

Longitudinal mass velocity, G_w

$$G_w = \frac{M_s}{3600 \times A_n}$$

$$= \frac{375 \times 500}{3600 \times 40.3}$$

$$= 1.3 \text{ lb/ft}^2\text{-sec} \checkmark$$

Cross flow mass velocity, G_m

$$G_m = \frac{M_s}{3600 \times BP \times D_f} \qquad (\text{Ref. } 23, \text{p. } 172)$$

BP = Baffle spacing

$= 3.75$ ft (Ref. 15)

D_f = free diameter

$= \left(9 \times (1.1 - 0.75)/1.1\right)$

$= 2.86$

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$$G_w = 375 \times 500 / (3600 \times 3.75 \times 2.86)$$

$$= 4.9 \ lb/ft^2\text{-}sec \ ✓$$

$$G_s = (G_m . G_w)^{1/2}$$

$$= (1.3 \times 4.9)^{1/2}$$

$$= 2.5 \ lb/ft^2\text{-}sec \ ✓$$

$$Re = \frac{\rho V d}{\mu} \cdot \frac{1}{g_c}$$

$$= \frac{G_s . D_{es}}{\mu} \cdot \frac{1}{g_c}$$

$$= \frac{2.5 \times 0.11}{9.5 \times 10^{-6}} \times \frac{1}{32.2}$$

$$= 900$$

From figure 5.13 of Reference 23,

$$\frac{h_o D_{es}}{k} \left[\frac{C_p \mu}{k} \right]^{-1/3} \cdot \left[\frac{\mu}{\mu_w} \right]^{-0.14} = 15$$

with, $\frac{C_p \mu}{k} = \frac{1 \times 9.5 \times 10^{-6}}{0.38} \times 32.2 \times 3600$

$= 2.9$

$\frac{\mu}{\mu_w} \simeq 1$

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$h_o = 15 \times (2.9)^{1/3} \times 0.38 / 0.11$

$= \underline{74}$ Btu/hr-ft²-°F ✓

Overall heat transfer Coefficient, U

Using,

$h_i = 576$ Btu/hr-ft²-°F

$h_o = 74$ Btu/hr-ft²-°F

and the fouling factor and tube wall resistance as given on page 57,

$$U = \left[\frac{1}{576} + 2\times10^{-4} + 4.5\times10^{-4} + \frac{1}{74}\cdot\frac{0.75}{0.64}\right]^{-1}$$

$= (0.0182)^{-1}$ ✓

$\underline{\underline{U = 55 \text{ Btu/hr-ft}^2\text{-°F}}}$ ✓

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Steam Generator Effectiveness, ε

$C_{min} = 375 \times 500 \times 1$ Btu/hr-°F
$= 187500 \times 1$ Btu/hr-°F

$C_{max} = 2355 \times 10^3 \times 1$ Btu/hr-°F ✓

$\frac{C_{min}}{C_{max}} = 0.1875 / 2.355$
$= 0.08$ ✓

$AU / C_{min} = 27700 \times 55 / 187500$
$= 8$ ✓

From Figure 2-23 of Reference 24,

$\varepsilon = 1.$

Therefore the auxiliary water will leave the steam generator at the RCS average temperature of 200°F. For conservatism 195°F is used as the cooling water exit temperature from the steam generator

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Heat Removal Capacity

With the auxiliary feedwater flow at 375 gpm and the steam generator effectiveness equal to 100%, the heat removal capacity of the auxiliary feedwater system is calculated below.

At transition to single phase mode:

$T_e = 212°F$

$T_i = 80°F$

$\dot{m} = 375 \text{ gpm} \times 500 (\text{lb/hr})/\text{gpm}$

$= 187500 \text{ lb/hr}$

$\dot{q}_{212} = 187500 \, (212-80)$

$= 24.8 \times 10^6 \text{ Btu/hr}$

At cold shutdown

$T_{av} = 200°F$

$T_H - T_C \simeq 9°F$ (from p: 53 at ~70 hr.)

Therefore,

$T_H = 204.5$

$T_C = 195.5$

Since $\varepsilon = 1$,

$T_e = 200°F$ (use 195°F, conservatively)

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Therefore,

$$q'_{200} = 187500\ (195-80)$$
$$= 21.6\times10^{6}\ Btu/hr.$$

The heat removal capacities calculated above must match the decay + sensible heat removal rates from the primary system. Assuming that the primary system is cooled at the following rates (to be verified later in the calculation),

$$\frac{dT}{dt} = 4.8\ ^\circ F/hr \qquad for \quad 350 < T \leq 212^\circ F$$

$$\frac{dT}{dt} = 1.2\ ^\circ F/hr \qquad for \quad 212 < T \leq 200^\circ F$$

and using 0.52×10^{6} Btu/°F sensible heat capacity for the primary system (from p: 11),

$$q'_{s,212} = 4.8\times0.52\times10^{6}$$
$$= 2.5\times10^{6}\ Btu/hr$$

$$q'_{s,200} = 1.2\times0.52\times10^{6}$$
$$= 0.6\times10^{6}\ Btu/hr$$

The decay heat that can be removed from the primary system at these points, are,

$$q'_{D,212} = 24.8\times10^6 - 2.5\times10^6$$
$$= 22.3\times10^6 \ Btu/hr$$

$$q'_{D,200} = 21.6\times10^6 - 0.62\times10^6$$
$$= 21\times10^6 \ Btu/hr.$$

The corresponding time points are obtained from the decay heat curve (shown on the next page) as,

$$t_{212} = 59 \ hr.$$
$$t_{200} = 69 \ hr. \quad (\text{Take } 72 \text{ hr, for conservatism})$$

These time points define the following cooldown rates,

$$\frac{dT}{dt} = \frac{350-212}{59-30}$$
$$= 4.8\,°F/hr \qquad \text{for} \qquad 350 < T \leq 212$$

and,

$$\frac{dT}{dt} = \frac{212-200}{69-59}$$
$$= 1.2\,°F/hr \qquad \text{for} \qquad 212 < T \leq 200$$

as assumed before.

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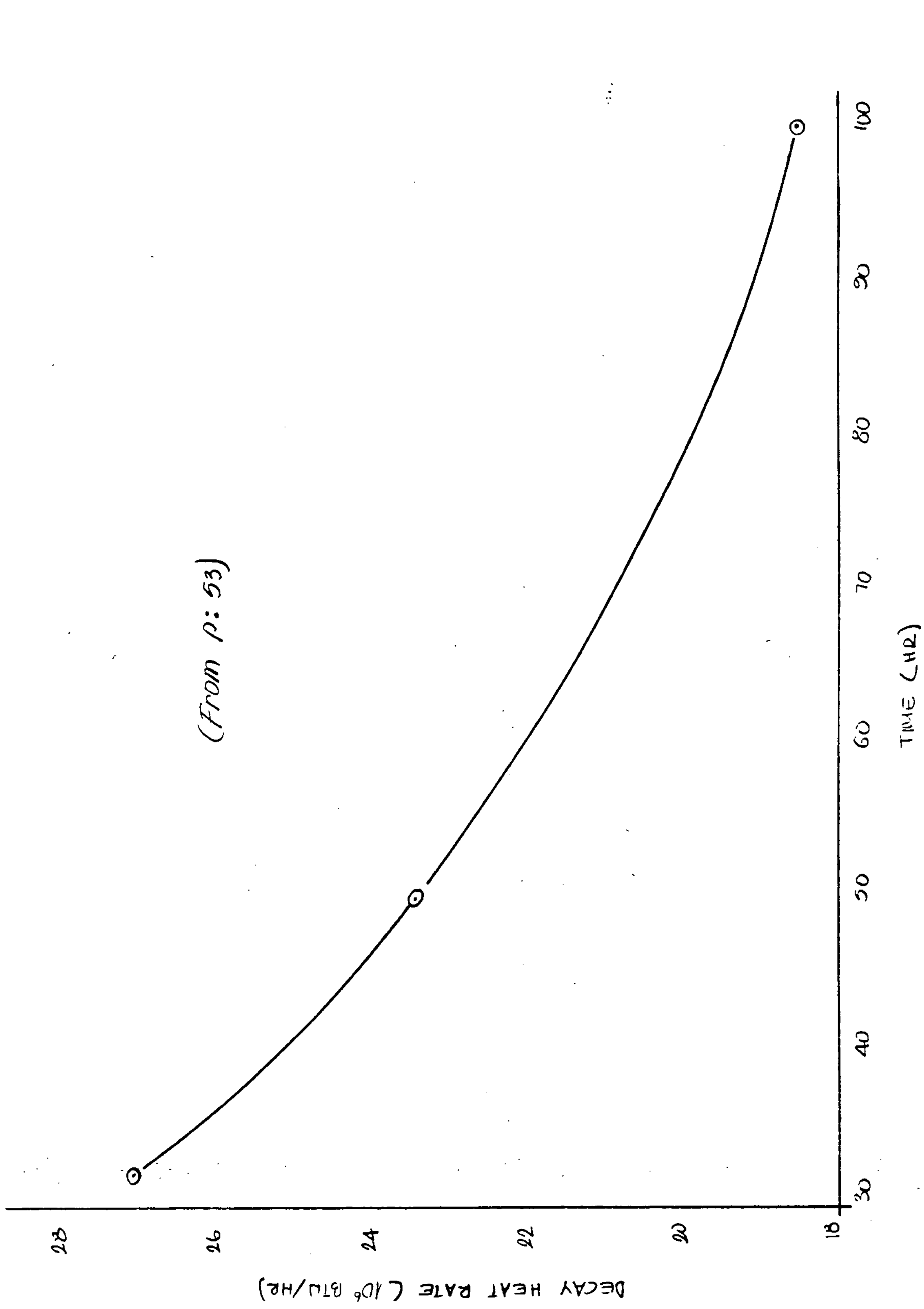

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Cooling Water Consumption

The amount of water consumption to achieve and maintain cold shutdown is calculated from the system energy balance.

Phase I - Steaming Mode

Integrated Decay Heat = 2×10^9 Btu (Fig. 3-6)

h_{in} (Cooling wat.) = 48 Btu/lb.

h_{ex} (Sat. Steam at 212°F) = 1150 Btu/lb.

$$V_w = \left[2 \times 10^9 / (1150 - 48)\right] \times \frac{1}{62} \times 7.48$$

$= 220\,000$ Gal.

Phase II - To achieve and maintain cold shutdown at 120°F for up to 1000 hr.

h_{in} = 48 Btu

h_{ex} = 153 Btu (Hot water at 190-5 = 185°F)

Integrated Decay Heat = 13×10^9 Btu

$$V_w = \left[(13 \times 10^9 - 2 \times 10^9) / 153 - 48\right] \times \frac{7.48}{62.}$$

$= 12.7 \times 10^6$ Gal

$\simeq 13{,}000{,}000$ Gal.

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Cooling Water Consumption

The amount of cooling water consumption to achieve and maintain the cold shutdown at 200°F is calculated from the system energy balance.

Phase I - Steaming Mode $(0 < t \leq 59 \text{ hr.})$

$$\Delta H + SH = 2 \times 10^9 \text{ Btu}$$

$h_{in} = 48$ Btu/lb (water at 80°F)

$h_{ex} = 1150$ Btu/lb (saturated steam at 212°F)

$$V_w = \frac{7.48}{62.2} \left(\frac{2 \times 10^9}{1150 - 48} \right)$$

$$= 220 \times 10^3 \text{ Gal.}$$ ✓

Phase II - Cold Shutdown $(0 < t \leq 72 \text{ hr.})$

$$\Delta H + SH = 2.3 \times 10^9 \text{ Btu}$$

$$V_w = 220 \times 10^3 + \frac{7.48}{62.2} \times \frac{(2.3 - 2.) \times 10^9}{(195 - 80)}$$

$$= 535 \times 10^3 \text{ Gal.}$$ ✓

NOTE:

ΔH = Decay heat

SH = Sensible heat

$\Delta H + SH$ values are read from Figure 3-6.

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Phase III - Cold Shutdown ($0 < t \leq 100$ hr.)

$\Delta H + SH = 2.9 \times 10^9$ Btu

$$V_w = 535 \times 10^3 + \frac{(2.9 - 2.3) \times 10^9}{195 - 80} \times \frac{7.48}{62.2}$$

$$= 1160 \times 10^3 \text{ Gal.}$$ ✓

Phase IV - Cold Shutdown ($0 < t \leq 1000$ hr.)

$\Delta H + SH = 14 \times 10^9$

$$V_w = 1160 \times 10^3 + \frac{(14 - 2.9) \times 10^9}{195 - 80} \times \frac{7.48}{62.2}$$

$$= 12800 \text{ Gal.}$$ ✓

Cooling water consumption is summarized below

Time (hr)	Cooling water Consumed (Gal.)
60	220×10^3
72	535×10^3
100	1160×10^3
1000	12800×10^3

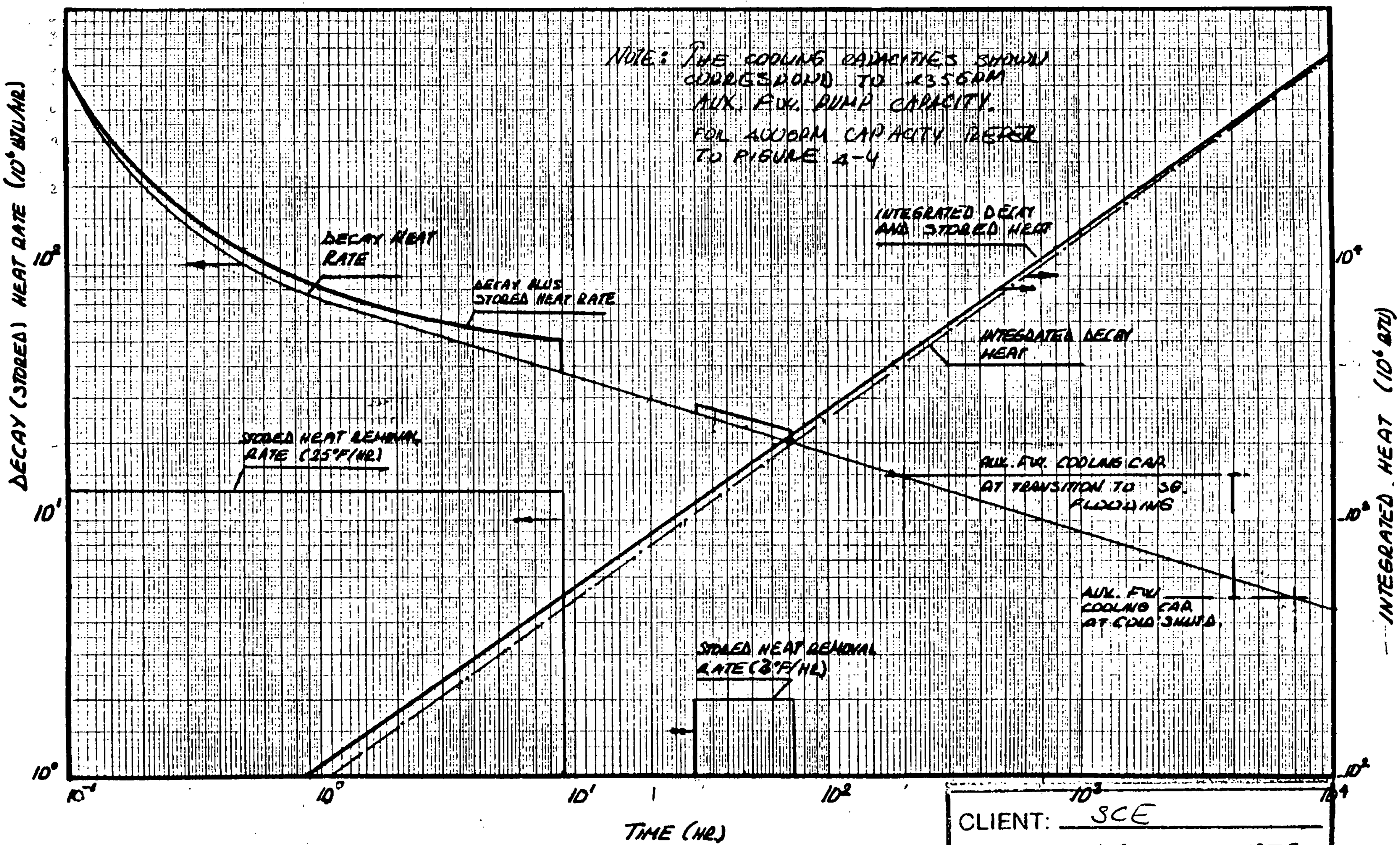

FIGURE 3-6 - PRIMARY SYSTEM HEAT REMOVAL RATE

CLIENT: SCE	
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3.9 Boron Concentration

Prior to initiation of cold shutdown, the reactor coolant boron concentration is increased to the shutdown concentration. Figure 2.74 of Reference 7 present Boron Removal/Addition rates after load reduction to zero power. Following values have been read from this figure:

Time After Shutdown (hr.)	0	5	10	15	20	25	30	35	40	45	50	55	60	65
Rate of Change of Boron (PPM/HR)	0	13	22	22	18	16	14	12	9	7	4	2	0	

Assuming that Boron is added in the form of Boric Acid (H_3BO_3) from a 12 percent Solution, the required rate of addition is determined from,

$$\frac{d}{dt}(MB) = \dot{m} b \times \left(\frac{12}{100}\right) \times \left(\frac{11}{62}\right)$$

where,

M = Primary system coolant inventory, 300000 lb
B = Primary system Boron concentration
$\dot{m}$ = Coolant addition rate (make up)
b = Concentration of Boric Acid solution in the make up water

Noting that, M = Constant,

$$\dot{m} = 2\ GPM/loop \times 3\ loops \times \frac{1}{7.48} \times 62\ \frac{lb}{ft^3} \times 60\ \frac{min}{hr}$$

$$\cong 3000\ lb/hr.$$

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$$\frac{dB}{dt} = \left(\frac{\dot{m}}{M}\right) \cdot b \times \frac{11}{62} \times \frac{12}{100}$$

from which

$$b = 4700 \ \frac{dB}{dt}$$

with dB/dt known from the previous page, the concentration of 12% Boric Acid Solution in the make up water is:

Time (Hr.)	5	10	15	20	25	30	35	40	45	50	55	60	65
b (lb/lb)	0.	.06	.11	.11	.09	.08	.07	.06	.04	.03	.02	.01	0.
Rate (lb/hr)*		180	330	330	270	240	210	180	120	90	60	30	0.

By integrating the rate of boric acid addition the amount of Boric Acid solution needed is determined. This is:

Amount of 12% Boric Acid Solution = 10200 lb

$\simeq$ 1270 Gal.

---

* Rate of addition of 12% Boric Acid Solution to satisfy the required Boron concentration

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If the make-up is supplied from the raw water storage tank (RWST) which contain 3750 ppm Boron (equivalent of 2.1% Boric acid solution *)

$$M \cdot \frac{dB}{dt} = \dot{m} \times PPM \times 10^{-6}$$

$$\dot{m} = (300000 \times 10^{6} / 3750) \frac{dB}{dt}$$
$$\dot{m} = 8 \times 10^{7} \frac{dB}{dt}$$

Again, using the dB/dt values given previously

Time (hr)	0	5	10	15	20	25	30	35	40	45	50	55	60	65
$\dot{m}$ (lb/hr)		0	1040	1760	1760	1440	1280	1120	960	720	560	320	160	0
Galons Pumped			313	1160	2220	3185	4000	4720	5350	5860	6250	6520	6670	6720

By integrating this rate, the amount of 3750 PPM borated water that needs to be supplied from the RWST is:

$$M_{RWST} = 55600 \text{ lb}$$

or

$$\simeq (55600/62.4) \times 7.48$$
$$= 6670 \text{ Gal}$$

$$* \; \% H_3BO_3 = \left(PPM \times 10^{-6} \times \frac{62}{11}\right) \times 100$$

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CALC NO TH1

3.10 Containment Sump Capacity

Based on the assumption that for every two gallons injected into the reactor coolant system one gallon leaks into the containment through the RCS pump third seal.

The leakage into the containment sump is contributed from the following sources:

RCS pumps : (2 gpm/loop) x 3 loops

= 6 gpm

Unknown Sources : 1 gpm (tech. spec. requirements)

Known sources : 5 gpm

TOTAL = 6+1+5 = 12 gpm

With the containment sump capacity equal to 295×10^3 Gal., at 12 gpm it will take,

$$295 \times 10^3 / (12 \times 60) = 410 \text{ hr.}$$

to fill the containment sump.

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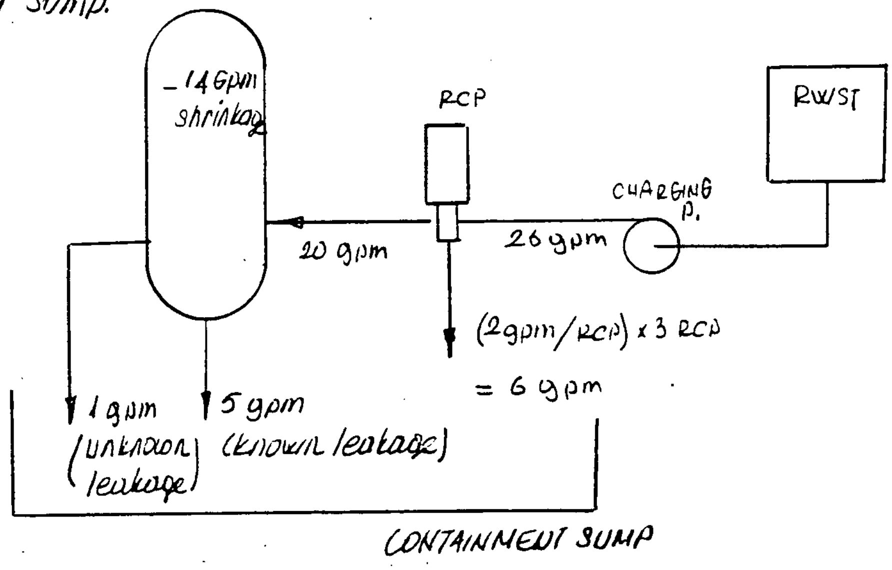
JOB NO 0310-027-1373

CALC NO THI

Charging System

The charging system is required to provide sufficient flow into the primary system to compansate for the shrinkage due to cooldown and for the leakage from the primary system. Following the reactor scram and containment isolation the charging pump is aligned to take suction from the RWST. The flow inventory is shown below. The required charging pump flow is 26 gpm of which 12 gpm eventually collects in the containment sump.



The 14 gpm shrinkage is obtained from page 44 corresponding to 8400 galons shrinkage during the first 10 hours, i.e., 8400/(10x60) = 14 gpm.

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4.0 RESULTS AND CONCLUSIONS

The study has indicated that the use of the steam generators at SONGS 1 to achieve and maintain cold shutdown is possible. The components that are essential to perform this function are shown in the schematics of Figure 4.1. Primary functions of the system is to:

- Remove the decay heat
- Achieve and maintain cold shutdown at 190°F
- Satisfy reactivity control requirements
- Satisfy primary system pressure control.

Essential elements of the system (excluding the instrumentation) are:

- Reactor vessel
- Steam generators
- Pressurizer
- Coolant reservoirs (Condensate Storage Tank, Auxiliary Feedwater Tank, Reservoir)
- Motor driven auxiliary feedwater pump

. Charging pump
. Refueling Water Storage Tank
. Emergency Thermal Barrier Pump
. Associated piping and valves

The constraints and the limitations imposed upon the system are discussed below.

Cooldown Rate: The recommended cooldown rate of Reference 1 which is illustrated in Figure 3.2 can be maintained. This cooldown rate consists of 25°F/hr initial cooldown to 350°F, 20 hr. Soak at this point followed by a cooldown rate of 10°F/hr or less to cold shutdown conditions. In this study the final phase of the cooldown is carried out at approximately 5°F/hr so that the decay Heat removal requirement at the point of transition to single-phase operation can be matched by the auxiliary feedwater cooling capacity. The cooldown is terminated at 190°F and maintained there for an indefinite period of time.

Primary System Pressure Control: Primary System pressure is limited by primary system subcooling and Nill Ductility Transition Temperature Requirements. These limits are

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CALC NO THI

indicated by the curves P_A and P_B in Figure 4.4. Also shown in this figure is the primary system pressure as determined by the natural cooldown rate of the pressurizer. Examination of these curves indicates that:

1. The required degree of subcooling to prevent the void formation in the upper head is marginally maintained during the early part of the cooldown (up to the 8th hour). Beyond this point the degree of subcooling is substantially greater than what is required.

2. The nill ductility requirement is maintained up to 35th hour. At this point the primary system pressure exceeds the nill ductility pressure limit and stays above for the rest of the cooldown.

In consideration of the first observation it can be said that pressurization of the primary system through external means (i.e., activating the pressurizer heaters or introducing high pressure nitrogen into the pressurizer) will not be necessary. This statement, however, must be viewed in the light of the assumptions used in this study. Namely the assumptions

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of no mixing at the surge line and the initial water volume of 630 ft^3. If mixing occurs, or if the initial water level is less than the normal, the cooldown rate will be somewhat accelerated. These conditions have not been considered in this study, and if examined may indicate a need for external pressurization.

In consideration of the second observation there is an obvious need to accelerate the depressurization after the 35th hour. This timing corresponds to the conditions of this study and may show variations depending on the initial conditions and the shutdown process followed during the early parts. Depressurization can be accelerated by the use of the relief valves and/or the pressurizer spray.

Natural Circulation: The configuration and the hydraulic resistance of the primary system is adequate to establish and maintain a natural circulation so that the decay as well as the stored heat can be transported away. Core circulation and the driving temperature difference are shown in Figure A.3. Near cold shutdown there is enough buoyancy head to maintain 3 percent nominal core flow

Reactivity Control: Following sustained operation at 100% power, approximately 160 lbs. of Boron must be added to the RCS to achieve 5 percent shutdown margin. This amounts to 700 ppm Boron concentration in the primary system and requires:

- 1270 Galons of 12 percent Boric Acid Solution from the Boric Acid Tank, or
- 6000 Galons of 3750 ppm Borated water from the RWST.

The required Boron addition is shown in Figure 3.5. As can be seen this amount can be accomadated by the volume provided by the shrinkage of the RCS due to cooldown.

Auxiliary Feedwater Capacity: The auxiliary Feedwater System has the ability to remove the decay heat and the stored heat from the primary system by way of the steam generators. with the configuration as shown in Figure 4.1, the auxiliary feedwater pumps (G-10S) will be operating against a pressure head much less than the design pressure head. As a result the is expected to increase from the 235 GPM nominal to 400 GPM. The NPSH available at this point is greater than the required NPSH by approximately 8 ft.

Because of the increased discharge the of the pump, the cooling capacity increases in the same proportion. The cooling capacities provided by the Auxiliary Feedwater System are shown in Figure 4.2 in the steaming as well as the Single Phase Operation Mode. As can be seen from this Figure the cooling capacity provided by the Auxiliary Feedwater pump G-10S is sufficient to achieve shutdown before 72 hrs.

The amount of coolant required is:

At 60 hrs (Point of Transition)	: 220×10^3 Gal
At 72 hrs (Cold Shut down)	: 535×10^3 Gal
At 100 hr	: 1160×10^3 Gal
At 1000 hr	: 12800×10^3 Gal

△1

The cooling water consumption is shown in Figure 3.2.

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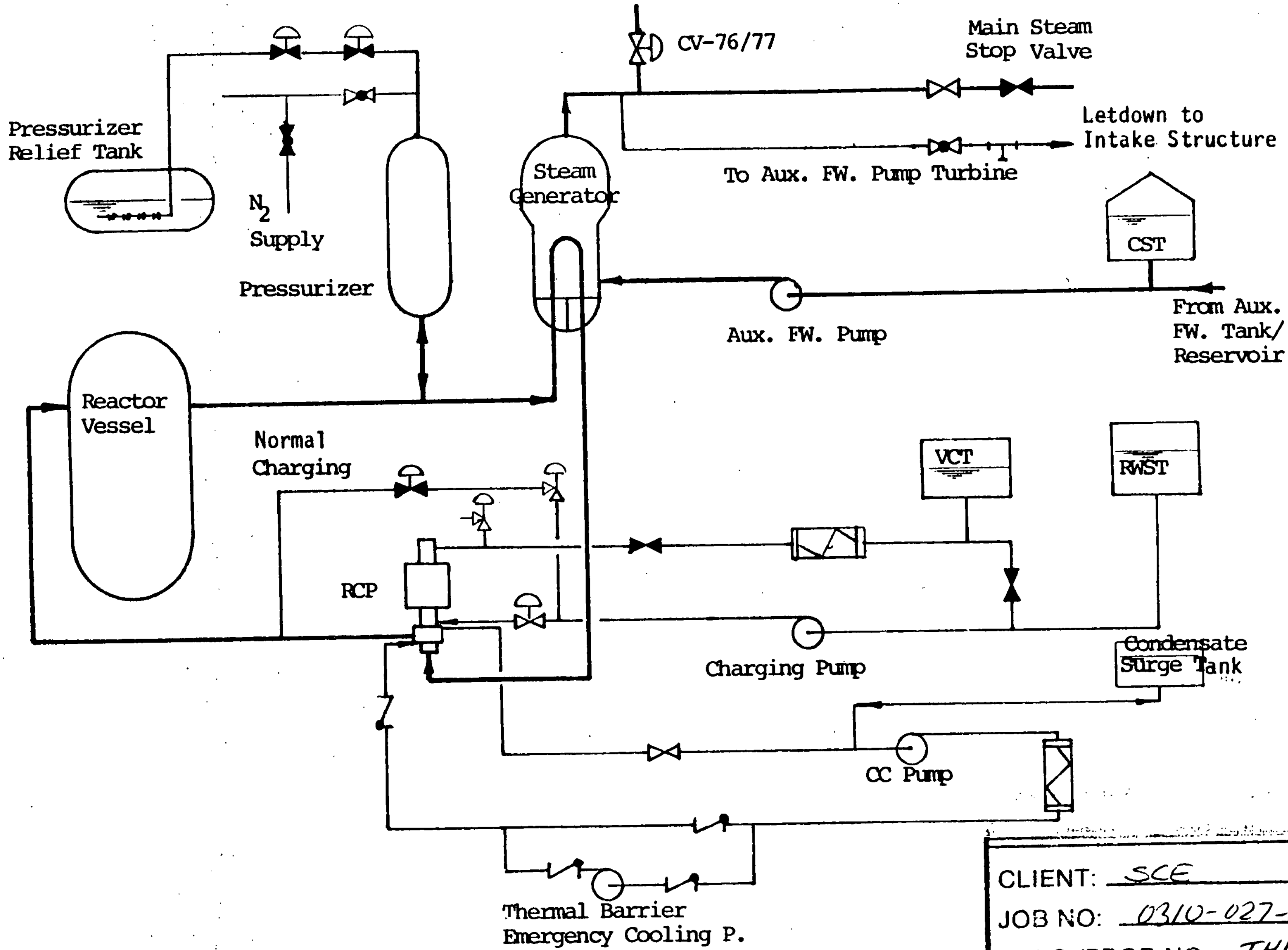

FIGURE 4-1 - SYSTEM SCHEMATIC

CLIENT: SCE	
JOB NO: 0310-027-1373	
CALC./PROB NO: THI	
BY: TD	DATE: 1/14/84
CHKD: [illegible]	DATE: 1/24/94

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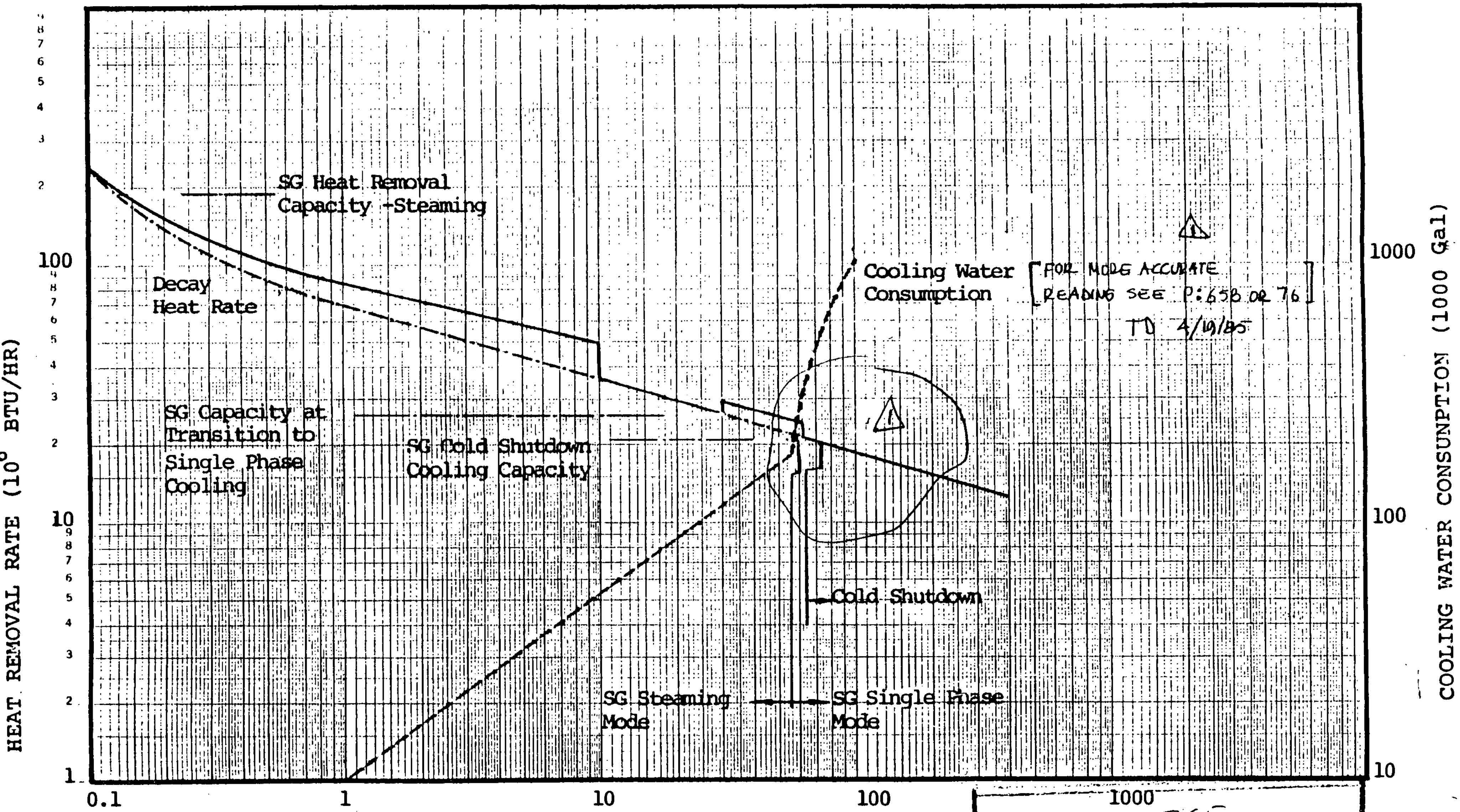

FIGURE 4-2 - PRIMARY SYSTEM COOLING REQUIREMENTS

CLIENT: SCE	
JOB NO: 0310-027-1373	
CALC./PROB NO: THL	
BY: TD	DATE: 1/16/84
CHKD: [illegible]	DATE: 1/24/84

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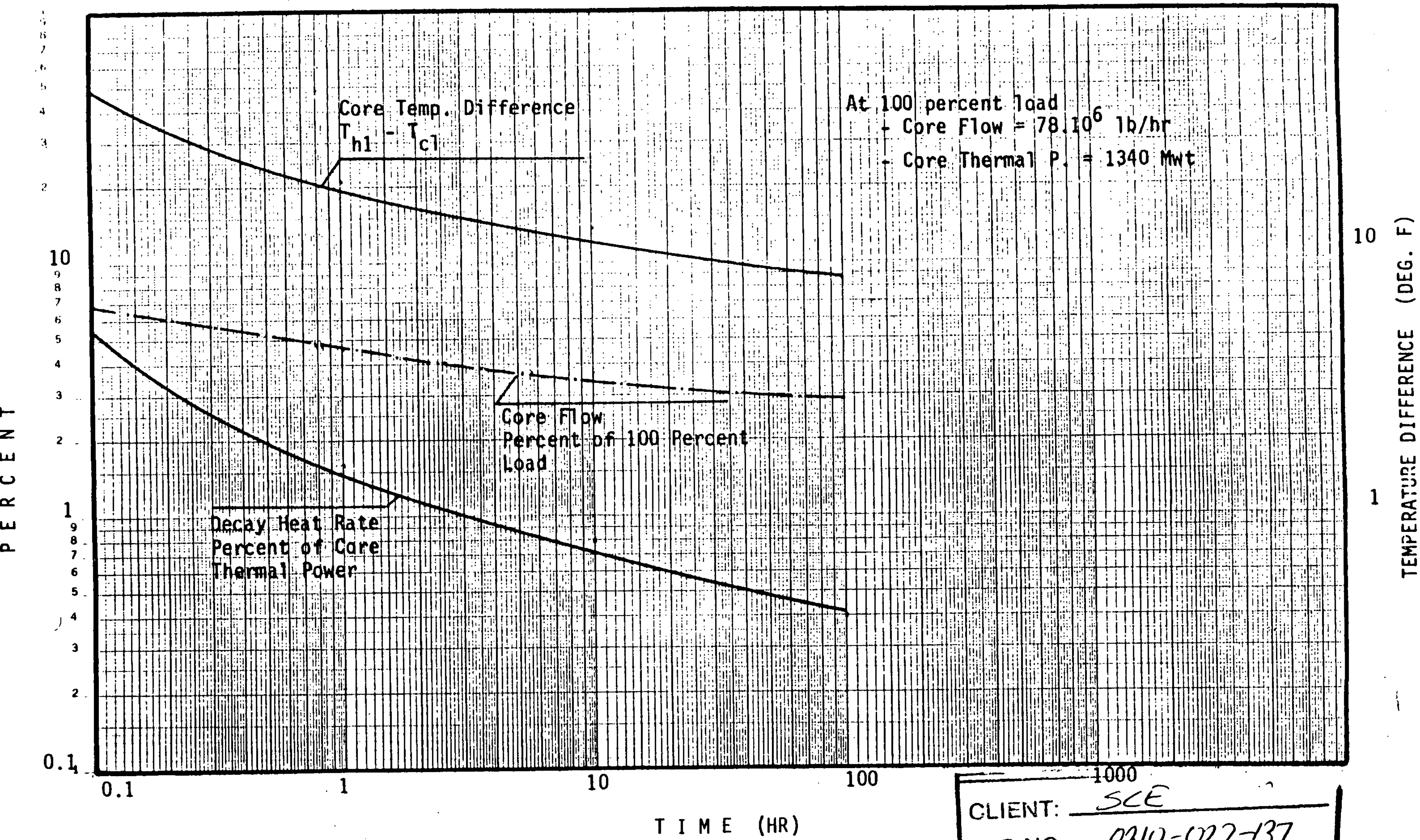

FIGURE 4-3 NATURAL CIRCULATION CORE FLOW RATE AND TEMPERATURE DIFFERENCE

CLIENT: SCE
JOB NO: 0310-022-137
CALC./PROB NO: TH1
BY: TD DATE: 1/16/84
CHKD: [illegible] DATE: 1/24/84

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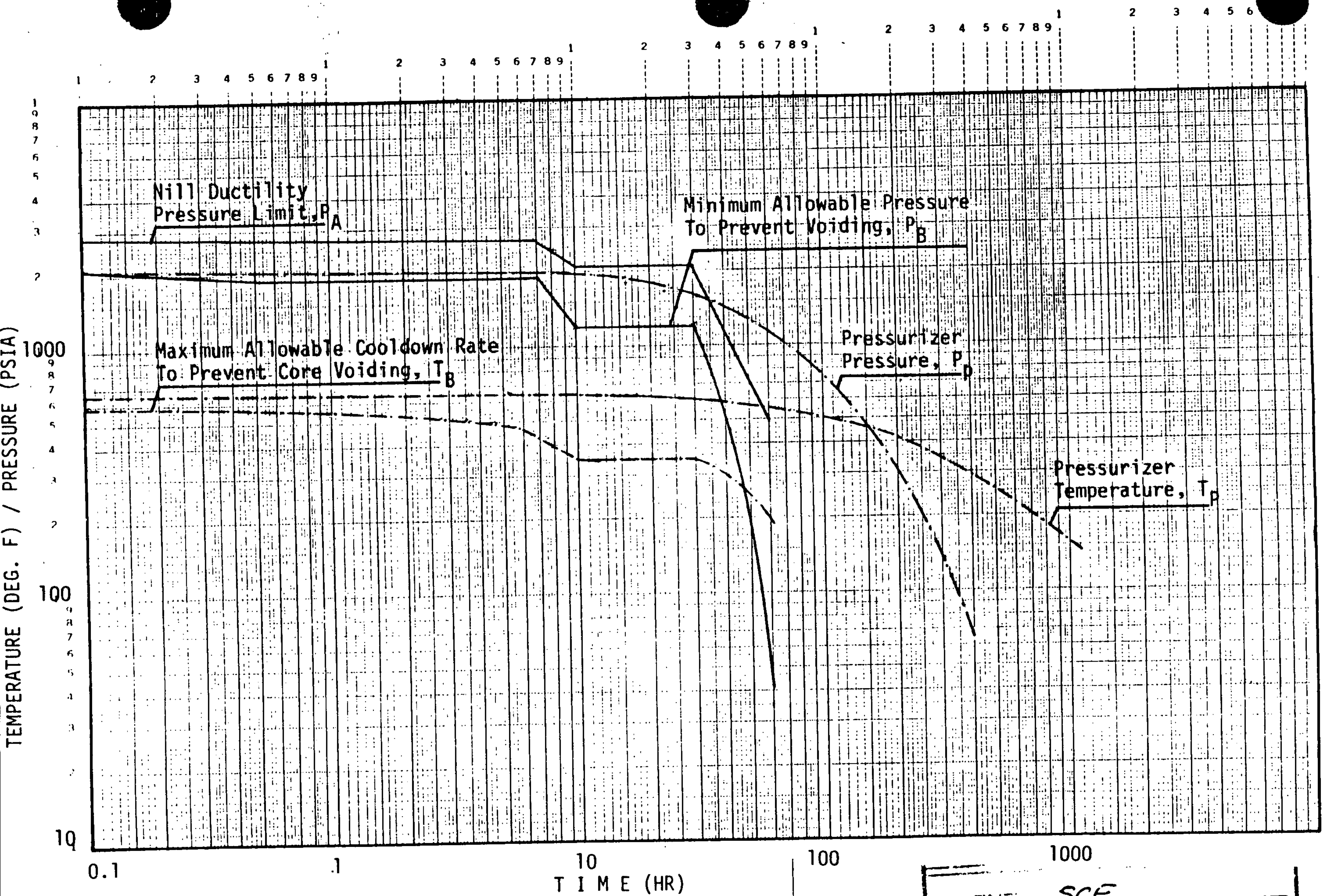

FIGURE 4-4 - PRIMARY SYSTEM COOLDOWN RATE LIMITATIONS

CLIENT: SCE
JOB NO: 0310-027-1373
CALC./PROB NO: TH1

BY: TD	DATE: 4/3/84
CHKD: NMo	DATE: 4/3/84

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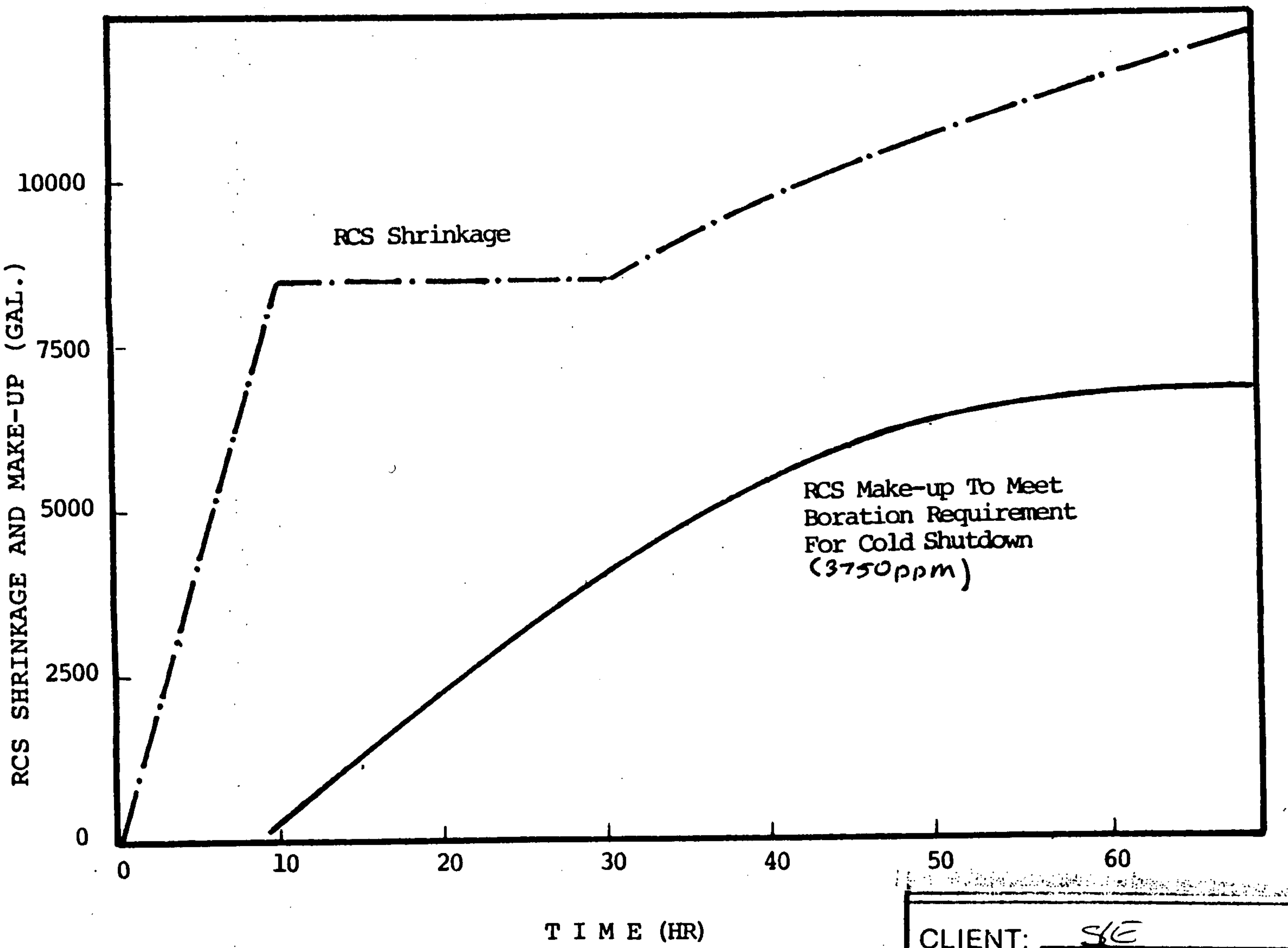

FIGURE 4-5 - PRIMARY SYSTEM MAKE-UP REQUIREMENTS

CLIENT: S&E	
JOB NO: 03/0-027-1373	
CALC./PROB NO: TMI	
BY: TD	DATE: 1/16/84
CHKD: OMC	DATE: 1/24/84

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