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NUCLEAR REGULATORY COMMISSION '84 MAY 31 A10:15

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
CAROLINA POWER & LIGHT COMPANY	)	
AND NORTH CAROLINA EASTERN	)	Docket No. 50-400 OL
MUNICIPAL POWER AGENCY	)	50-401 OL
(Shearon Harris Nuclear Power	)	
Plant, Units 1 and 2)	)	

AFFIDAVIT OF ROBERT W. CARLSON

County of Allegheny)
SS:
Commonwealth of Pennsylvania)

Robert W. Carlson, being duly sworn according to law, deposes and says:

1. My name is ROBERT W. CARLSON. My business address is P.O. Box 355, Pittsburgh, Pennsylvania 15230. I am employed by the Westinghouse Electric Corporation as a Principal Engineer in the Reactor Coolant and Steam Generator Support Systems Group of the Nuclear Technology Division.

2. I received a Mechanical Engineering degree from Stevens Institute of Technology in 1953 and a Master of Science degree in Nuclear Engineering from Massachusettes Institute of Technology in 1959. I also attended Case Institute of Technology for two years, from 1965 to 1967, as a full-time graduate student in the field of Thermal Sciences.

3. I accepted a position in 1953 as a Boiler Division student engineer with the Babcock & Wilcox Company. After the one-year program, I joined the Babcock & Wilcox Company Atomic Power Division. In 1955, I took a leave of absence for military service and MIT Graduate School. I returned to Babcock & Wilcox in 1959 and was later promoted to the position of Senior Engineer in

the Atomic Power Division. I joined the Westinghouse PWR Systems Division as a Senior Engineer in 1967. My initial duties were as a reactor core thermal and hydraulic designer. In 1975, I was promoted to my present position of Principal Engineer.

4. During 1975 and 1976, I participated in a test program conducted by Westinghouse at its Research and Development Center in Pittsburgh to investigate the bubble collapse waterhammer phenomenon. One objective of the test program was to gain a basic understanding of the bubble collapse phenomenon in horizontal pipe sections.

5. In 1977, I participated in a test program to investigate the potential for bubble collapse waterhammer in preheat steam generator designs, including the Shearon Harris type steam generator. I was responsible for the thermal and hydraulic design of preheater scale model test sections and the test vessel. I was also responsible for the initial evaluation of the test data.

6. In my present position, I meet, on behalf of Westinghouse, with utility customers and their architect-engineers to provide assistance in the design and operation of the plant, as recommended by Westinghouse, to minimize the potential for a waterhammer event.

7. Therefore, I have personal knowledge of the matters stated herein and believe them to be true and correct. I make this affidavit in support of Applicants' Motion for Summary Disposition of Eddleman Contention 45. This contention reads:

> SHNPP design cannot comply with the results of the Plant Waterhammer Experience Report, PWR S.G. (steam generator), feedwater, ECCS & Main Steam System waterhammer events evaluation (including systems effect) and potential resolutions now being prepared by NRC, and the CR and NUREG reports on the waterhammer question.

8. The purpose of this affidavit is:

- To describe those aspects of the design of the Shearon Harris Nuclear Power Plant (SHNPP) steam generators, feedwater system and emergency core cooling system (ECCS) relevant to the potential for waterhammer, and

- o To show that those features described provide for designs with minimized potential for unanticipated waterhammer events, and

- o To show that, even in the unlikely event that a waterhammer were to occur in one of the above systems, it would not be expected to affect safe plant operation.

9. The conclusions set forth in this affidavit are consistent with those reported by the NRC staff in NUREG-0927, "Evaluation of Waterhammer Occurrence in Nuclear Power Plants-Technical Findings Relevant to Unresolved Safety Issue A-1". In that report, the staff concludes that the overall incidence of waterhmmer in nuclear power plants has declined considerably in recent years. Although the staff finds that total elimination of waterhammer is not feasible, they conclude that the frequency and severity of waterhammers is significantly reduced through proper design. Moreover, the NRC staff reports that none of the waterhammer events which have occurred placed the plant in a faulted or emergency condition or resulted in a radioactive release. On the basis of these and other key findings, the NRC is not recommending hardware or design changes for existing plants or plants under construction in its resolution of Unresolved Safety Issue A-1.

10. Before discussing specific system design features, I will describe the mechanisms for water hammer. In general, there are two forms of waterhammer, classical (flow into voided region and suddent interruption of flow) and bubble collapse. In both cases, a change in water velocity leads to a change in pressure due to the inertia of the water. The two forms differ with respect to the mechanisms which cause the change in velocity.

11. In a classical waterhammer, the change in water velocity is typically the result of a sudden interruption of the flow stream or flow into a voided region. As an example of classical waterhammer, consider a pipe with water flowing inside. If a valve in the pipe is closed quickly, the water will be

brought to rest and, as a consequence, a sudden pressure increase will result at the valve. This change in pressure will travel as a wave back and forth in the pipe until it dissipates due to friction.

12. Bubble collapse waterhammer refers to a potential condition where initially a volume of steam is trapped within an enclosed region, for example, a horizontal section of pipe with water slugs on both sides. If the temperature of the water in the slugs is the same as that of the steam, the water and steam will be in equilibrium. However, if the slugs contain cold water which comes into contact with the steam, the steam will condense rapidly resulting in a sudden local decrease in pressure. A higher pressure behind the water slugs will cause them to accelerate towards each other. When they collide, an increase in pressure will result. This change in pressure will propagate back and forth in the water the same as in the classical waterhammer case.

13. The magnitude of the pressure change produced at the valve in the classical waterhammer example depends on the rate at which the valve is closed, the initial water velocity, and the density of the water. In the bubble collapse waterhammer example, the pressure change magnitude depends on the rate at which the steam is condensed and the pressure behind the water slugs.

I SHNPP STEAM GENERATOR

14. In paragraphs 15 thru 33 I will discuss those aspects of the SHNPP steam generator design which are relevant to the bubble collapse and classical waterhammer phenomenon.

15. The Carolina Power and Light ("CP&L") SHNPP utilizes a Westinghouse designed nuclear steam supply system (NSSS) consisting of three recirculating reactor coolant loops. Each loop contains a Westinghouse Model D-4 steam generator. Within each steam generator there are 4578 inverted U-shaped steam generator tubes, collectively referred to as the tube bundle. The tubes act as the pressure boundary between the primary (reactor coolant) water and the

secondary (steam producing) water. The tubes are secured at the end of each leg of the "U" to a thick steel plate known as the tubesheet. This acts as the primary-to- secondary barrier before the primary water enters the tube bundle. The hot reactor coolant water flows through the inside of the tubes. The tube bundle is immersed in relatively cool secondary water which is raised to steam producing temperatures by the transfer of heat through the walls of the steam generator tubes from the primary water to the secondary water. High quality steam exits the top of the steam generator and is used to drive turbines which in turn drive a generator to produce electricity. The presence of both steam and water on the secondary side of the steam generator accounts for the fact that the potential for bubble collapse waterhammer is a consideration in the design of the steam generator.

16. An outline drawing of a Model D-4 preheat steam generator is contained in Attachment 1 hereto. As shown in the figure, the preheat region is located on the cold leg side of the tube bundle and faces the feedwater inlet nozzle. In the Model D-4 steam generator, the incoming main feedwater flow enters the inlet water box and impinges on a wall that directs the water outward to fill the water box volume and downward to the preheater inlet pass located near the bottom of the steam generator before entering the tube bundle. See Attachment 2 hereto. The water then enters the tube bundle at the inlet pass, flows around the tubes and then upward around the tubes and baffles. This upward flow is "counter" to the direction of the flow of the primary water inside the steam generator tubes.

17. As shown in Attachment 1, the SHNPP steam generator contains, in addition to the main feedwater inlet nozzle, an auxiliary feedwater nozzle in the upper shell. One purpose of the auxiliary feedwater nozzle is to minimize the potential for bubble collapse waterhammer in the preheater region of the steam generator. As stated earlier, one of the elements required for bubble collapse waterhammer is cold water. Cold water acts as a heat sink which causes the condensation of the steam and collapse of the bubble. Although the probability of occurrence is remote, it is conceivable for steam pockets to form in the preheater section. Therefore, in order to minimize the potential for bubble collapse waterhammer, when it is necessary to introduce cold feedwater into the steam generator, the feedwater bypass system design directs

the cold feedwater thru the upper auxiliary feedwater nozzle to the steam generator upper shell region. In the upper shell region, the cold feedwater can mix with the bulk steam generator water in a region where steam pockets will not exist.

18. The design of the feedwater bypass arrangement for the SHNPP steam generators is based on the results of a comprehensive waterhammer test program carried out by Westinghouse, under my supervision, in 1977 and 1978. One-eighth scale models of preheat steam generator designs, including the Model D-4 design, were tested under simulated plant operating conditions, including pressures up to 1,000 psia. The test objective was to determine those conditions where bubble collapse waterhammer could occur in the steam generator and immediately adjacent upstream feedwater piping. All of the tests consisted of two steps: first, establishing conditions where steam would be present in the preheater region, and, second, introducing water at different conditions to condense the steam.

19. Two different types of tests were conducted. In one, referred to as Type A, the water level in the test vessel was lowered below the preheater section, a situation which could conceivably occur following the faulted condition of a main feedpipe rupture. Once the water level was verified to be below the preheater section, feedwater was introduced through the feedwater nozzle. Any resulting pressure pulses were measured and recorded. In Type B testing, the water level was maintained above the preheater section and steam was generated in the preheater region by means of electrically heated rods which simulated the steam generator tubes. Again, after the desired conditions were established, feedwater was introduced through the feedwater nozzle and any pressure pulses produced were measured and recorded. The Type B condition simulated normal and upset conditions for the steam generator, such as plant loading.

20. In addition to the initial water level in the test vessel, other principal variables in the test program were pressure, feedwater flowrate, and feedwater temperature. Tests were conducted at different pressures up to steam generator normal operating pressure. The feedwater temperature was varied from approximately 80°F to 250°F.

21. The most significant result of the test program was that waterhammer did not occur if the temperature of the feedwater was 250°F or higher. The design of the feedwater bypass system is based largely on this result. Results of this test program also indicated that the potential for bubble collapse waterhammer was significantly reduced at the pressures at which the steam generator normally operates. Although this further reduces the potential for a waterhammer event, no credit was taken for this finding in designing the bypass system.

22. A final test series was conducted to simulate the effect on the preheater of introducing cold feedwater (< 250°F) through the auxiliary feedwater nozzle. No waterhammer events were detected.

23. In addition to evaluating the potential for bubble collapse waterhammer in the preheater for various conditions of temperature, pressure and flow, the one-eighth scale test program also provided bubble collapse waterhammer loadings for input into the preheater structural analysis. The results of this analysis indicate that the steam generator primary coolant pressure boundary is maintained under normal, upset and faulted bubble collapse waterhammer loadings.

24. On the basis of these design features and testing, I conclude that there is minimum potential for bubble collapse waterhammer in the SHNPP steam generators. In addition, on the basis of the testing and subsequent structural analysis, in the unlikely event that a bubble collapse event did occur, the primary coolant pressure boundary would be maintained.

25. Two recent events which applicants have discussed in response to Mr. Eddleman's interrogatories dated March 26, 1984 occurred at two different operating nuclear plants with steam generators which were not manufactured or designed by Westinghouse. Damage was attributed in one case to waterhammer and in the other case to either waterhammer or fatigue.

26. In the first case, the event involved the feedring (sparger) of a feedring design steam generator. In this design, feedwater is normally provided to the steam generator thru the feedring (sparger) which is located

in the upper part of the steam generator vessel at the approximate elevation of normal water level. Since the SHNPP steam generators are of the preheat type and do not have feedrings (spargers), this particular event cannot happen at the SHNPP.

27. In the second case, the event involved a sparger inside the steam generators for injecting and distributing auxiliary feedwater. The sparger consisted of a horizontal, curved pipe section with an arc of approximately 120 degrees. The SHNPP design for injecting auxiliary feedwater into the steam generators is significantly different. Instead of a horizontal sparger the auxiliary feedwater is supplied through a simple upwardly inclined pipe section. Again, because of the fundamental differences in design, the incident involving the horizontal sparger cannot occur in the SHNPP steam generators.

28. Thus, an evaluation of the two recent events cited does not alter my previous conclusion that there is minimum potential for bubble collapse waterhammer in the SHNPP steam generators.

29. In addition to the bubble collapse waterhammer design considerations, the SHNPP Model D-4 steam generator is designed for classical type waterhammer loads resulting from events which can originate in the Feedwater System or Steam System.

30. Limiting classical waterhammer pressure loads acting through the steam generator main feedwater nozzle are considered for two specific events; a feedline rupture followed by rapid closure of the main feedwater check valves, and a steamline rupture resulting in a high flowrate through the main feedwater nozzle into the preheater. The feedline rupture-check valve rapid closure transient was considered assuming the maximum loading condition of instantaneous closure of the check valve from maximum possible reverse flow.

31. Westinghouse has analyzed the effect of these transients for the SHNPP steam generators. The results of the analysis show that the integrity of the steam generator is maintained and that safe operation of the steam generator is unaffected.

32. Limiting classical waterhammer pressure loads acting through the auxiliary nozzle are due to bypass line check valve closure resulting from reverse flow due to a main feedline rupture. As for the limiting loads acting through the main feedwater nozzle, safe operation of the steam generator is unaffected.

II MAIN FEEDWATER AND FEEDWATER BYPASS SYSTEMS

33. Having reviewed the design features of the steam generator which minimize the potential for and effects of waterhammer, I will now discuss the design of the feedwater system relative to the potential for bubble collapse waterhammer. Dean Shaw's affidavit discusses classical waterhammer in these systems. The basics of the feedwater system typical of that used at the SHNPP are shown in Attachment 3 hereto. The system includes a 16 inch main feedwater line which connects to the main feedwater nozzle. Four principal valves are associated with the main feedwater line; the main feedwater control valve, the main feedwater control valve bypass valve, the main feedwater check valve and the main feedwater isolation valve. A smaller (6 inch) diameter bypass line connects the main feedwater line, between the main feedwater control valve and the main feedwater check valve, to the steam generator auxiliary feedwater nozzle. The bypass line itself contains an isolation valve and two check valves.

34. During plant startup, feedwater is supplied to the steam generator only through the auxiliary nozzle. During plant loading (escallation in power), feedwater supply will be switched to include main nozzle supply only after the following criteria are satisfied:

(1) A minimum feedwater flowrate of approximately 15% of the full power flowrate is provided.
(2) The feedwater temperature is 250°F or higher as measured at the low points in the main feedwater piping.
(3) The section of main feedwater piping between the bypass line branch point (Point A, Attachment 3) and the main feedwater nozzle has been purged of cold water.
(4) The steam generator pressure is greater than 700 psia.
(5) The steam generator water level is within a specified range.

35. During plant unloading, the same criteria apply except that the feedwater flow is switched to only the auxiliary nozzle when the flowrate drops below approximately 15%.

36. The fact that these criteria must be satisfied to permit feedwater flow through the main nozzle makes it extremely unlikely that bubble collapse waterhammer will occur. This conclusion is consistent with that reached by the NRC in NUREG-0927 (page 2-22) regarding preheat steam generator waterhammer potential. Specifically, the NRC states that "the occurrence of an SGWH (Steam Generator Waterhammer) event in a PHSG (Preheat Steam Generator) would require multiple component failures (including several check valves and operator errors). Even if such an event occurred, it is not expected to have an adverse effect on plant safety or AFW system operability".

37. As indicated in Attachment 3, the Auxiliary Feedwater System connects to the feedwater bypass line. The Auxiliary Feedwater System provides feedwater to the steam generator through the feedwater bypass piping and the auxiliary feedwater nozzle in the event of a loss of heat sink accident, such as a feedwater pipe rupture.

38. One postulated phenomenon considered in the design of the SHNPP feedwater bypass system is that of steam backleakage from the steam generator into the feedwater bypass line and then into the Auxiliary Feedwater System piping.

39. The auxiliary nozzle connects inside the steam generator to an upwardly inclined pipe extension, the discharge end of which is below the normal operating water level in the steam generator. For steam to push back into the bypass piping, it would be necessary for the check valves, which are provided to restrict reverse flow to be leaking and for the steam generator water level to be below the auxiliary nozzle internal extension. If the water is kept at the normal operating level, steam cannot enter the internal extension and thus cannot enter the bypass piping.

40. The feedwater control system is designed to maintain the steam generator water level above the top of the auxiliary feedwater discharge pipe inside the steam generator. During normal plant operation, with the discharge pipe covered, only hot water and not steam could leak back into the bypass and Auxiliary Feedwater System piping, thus greatly reducing the potential for waterhammer.

41. Moreover, steam backleakage during normal power operation is very unlikely since system design is such that normally continuous flow is provided through the steam generator auxiliary nozzle which effectively prevents the backflow of steam from the steam generator.

42. During heatup, cooldown and hot standby operations, relatively small amounts of feedwater are supplied to the steam generator by the Auxiliary Feedwater System through the auxiliary nozzle. This system is designed to provide continuous feed rather than intermittent feed as much as possible, minimizing the potential for steam backleakage and the potential for waterhammer.

43. An additional design feature of the feedwater bypass system to minimize the potential for a water hammer of this type is the installation of two temperature sensors on the bypass piping inside containment close to the auxiliary feedwater nozzle of each steam generator. If the measured temperature values exceed a predetermined setpoint, an alarm is activated in the control room.

44. In the eventuality that the presence of steam is suspected in the bypass line, based on temperature data and water level status and history, the system can be recovered by slowly purging the bypass line using the Auxiliary Feedwater System at a rate of approximately 15 gpm.

45. Based on the design features of the auxiliary nozzle and its internal extension, the normal operating conditions, and the means provided for alarming and recovery from back leakage of steam if it should occur, the probability of bubble collapse waterhammer in the feedwater bypass line is minimized. This conclusion is consistent with that reached in NUREG/CR-3090

which evaluated the potential for waterhammer occurrence during Auxiliary Feedwater operation of preheat steam generators and concluded that the likelihood was extremely low. Furthermore, if a waterhammer event did occur, NUREG/CR-3090 concluded that the event should have no adverse effects on Auxiliary Feedwater system operation or plant safety.

III ECCS SYSTEM

46. Another system identified in the contention is the ECCS. The potential for waterhammer occurrence has been and continues to be a consideration in the design of the ECCS. As a result of this consideration, the Shearon Harris ECCS is inherently not susceptible to waterhammer type pressure pulses resulting from sudden check valve closure, sudden pump startups and stops, fast acting isolation valves and relief valve operation. Waterhammer is most easily dealt with in the design mode so that it will not occur during normal and transient conditions. The postulated waterhammer mechanisms listed above are layout dependent phenomena, resulting from interaction between various components within the system. These have historically not been identified as an issue in any Westinghouse 3 loop ECCS such as at SHNPP. Preoperational testing and years of operating history supports this position.

47. Another postulated waterhammer mechanism would be that due to voids in a water solid system. Voids within the ECCS are minimized through various design features as supplemented by procedural, and administrative constraints. Westinghouse provides information to the piping layout designer to minimize the potential for voids within the system. The architect engineer's utilization of this information will provide a design responsive towards minimizing voids. One layout consideration identified is to provide pump suction piping which is self-venting and free of potential gas pockets.

48. An additional recommendation made to the piping designer is to provide adequate venting capability of the system. Vents are to be provided in the high points of any piping loops where gas could collect and interfere with proper system operation.

49. Voids have been postulated in water solid systems as a result of leakage. However, due to the head provided by the Refueling Water Storage Tank, Accumulator Tanks and Boron Injection Surge Tank, the majority of the Safety Injection System is normally maintained at a pressure higher than atmospheric. As a result, any leakage in the system should be outward with water makeup from within. Makeup would be provided from the tanks identified.

50. Furthermore, the probability of pressure boundary leakage is extremely low due to the high quality standards applied for the design, construction, installation and inspection of the ECCS piping. The piping is essentially of welded construction with minimum potential for leakage. Stringent manufacturing inspections, pre-service inspections and inservice inspections provide for the leak-tight integrity of the system.

51. These aspects of the ECCS design take into consideration the mechanisms of ECCS waterhammer identified and evaluated in NUREG-2781. As a result of these design considerations, the potential for waterhammer in the SHNPP ECCS has been greatly reduced. Further, the NRC's review of waterhammer events as reported in NUREG/CR-2059, concludes that ECCS waterhammer events reported at pressurized water reactors have not had any adverse safety effect on a plant.

52. In summary, I am confident that the design of the SHNPP steam generator, main feedwater and feedwater bypass systems, and the ECCS minimize the potential and consequences of water hammer in those systems and that the issue of waterhammer in those systems at SHNPP is not a safety concern.

Robert W Carlson

Robert W. Carlson

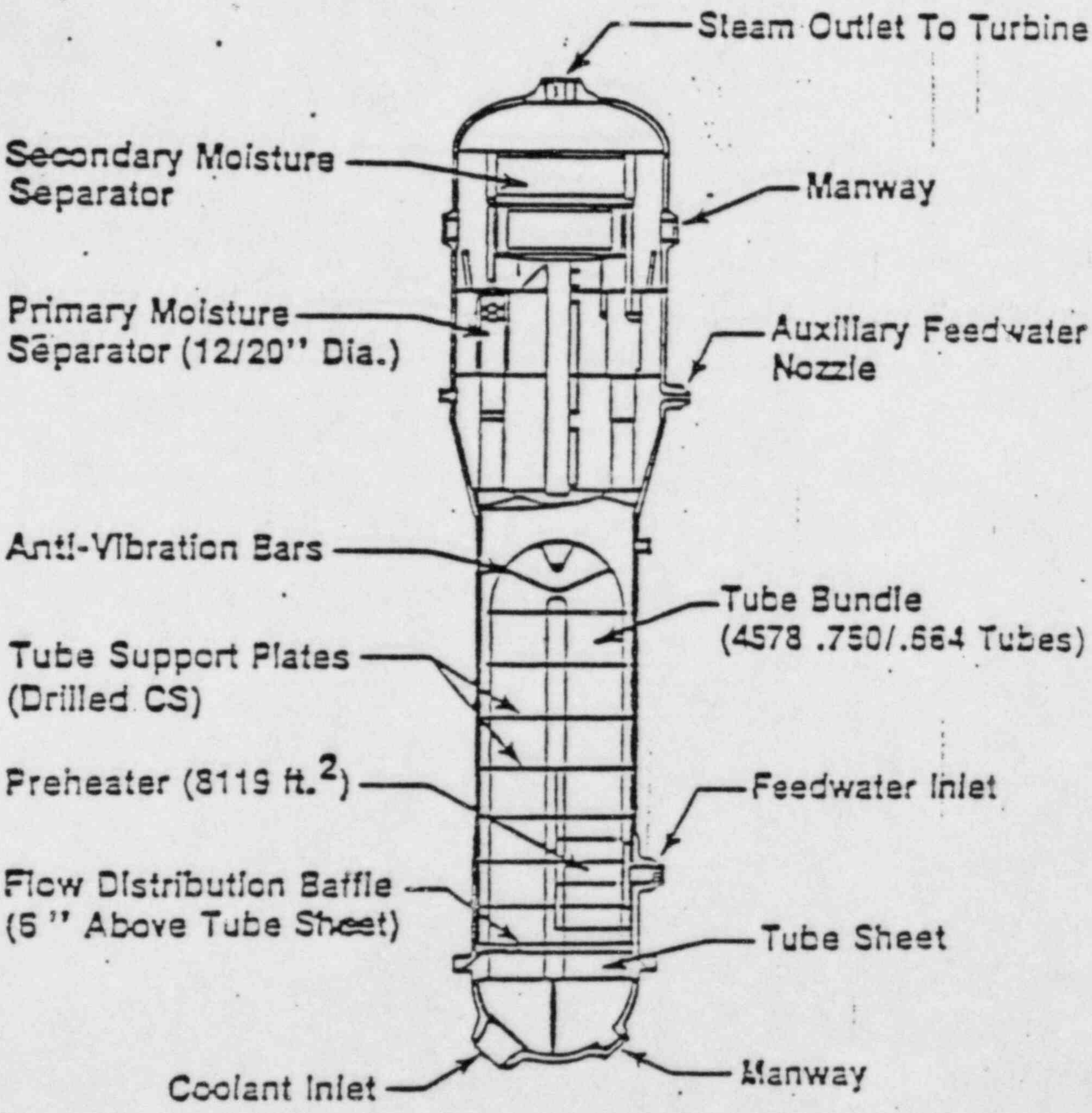
Sworn to and subscribed before me this 24th day of May, 1984.

Lorraine M. Piplica

Notary Public

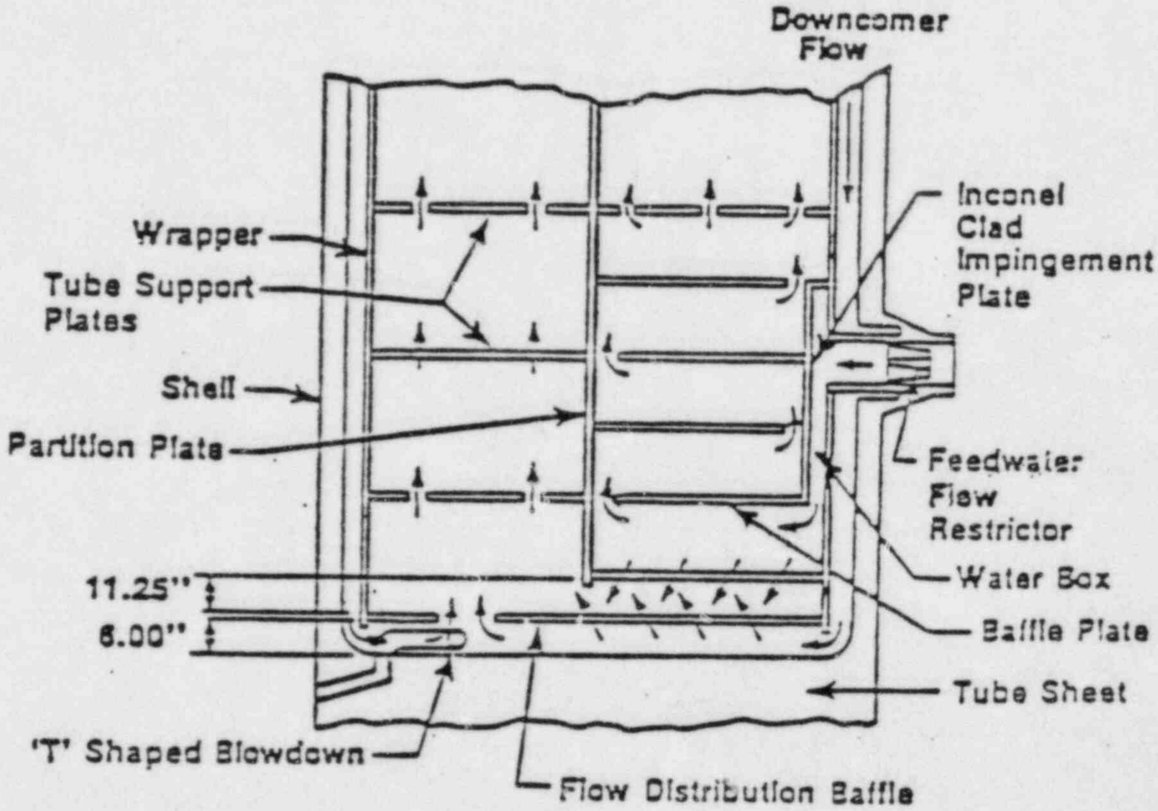
My Commission expires:

LORRAINE M. PIPLICA, NOTARY PUBLIC
MONROEVILLE BORO, ALLEGHENY COUNTY
MY COMMISSION EXPIRES DEC 14, 1987
Member, Pennsylvania Association of Notaries



ATTACHMENT 1

MODEL D-4 PREHEAT STEAM GENERATOR



ATTACHMENT 2

MODEL D-4 PREHEAT STEAM GENERATOR

MAIN FEEDWATER NOZZLE AND PREHEATER REGION

ATTACHMENT 3

TYPICAL FEEDWATER SYSTEM DESIGN