UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
COMMONWEALTH EDISON COMPANY	)	Docket No. 50-454-OLA
	)	50-455-OLA
(Byron Station, Units 1 and 2)	)	

TESTIMONY OF DR. LAWRENCE CONWAY CONCERNING STEAM GENERATOR TUBE INTEGRITY (STEAM GENERATOR DESIGN)

Submitted on behalf of
the Applicant, Commonwealth Edison
Company in Response to DAARE/SAFE
Contention 9c and League Contention 22

February 25, 1983

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SUMMARY

The testimony of Dr. Lawrence Conway sets forth his professional qualifications as an expert and describes the design changes implemented by Westinghouse to enhance resistance to tube degradation for the model D4 and D5 steam generators installed at the Byron Station. After first explaining the function of Westinghouse steam generators, Dr. Conway identifies three means for dealing with potential steam generator tube degradation, namely the selection of corrosion-resistant materials and the adoption of design configurations and changes to minimize areas for chemical concentrations and to reduce the level of mechanical stress.

Dr. Conway enumerates and describes the various design features implementing the foregoing principles that have been incorporated in the Byron Station steam generators; and he concludes that these steam generators represent and embody the very best design features from the perspective of minimizing tube degradation, overall performance and safety.

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TESTIMONY OF DR. LAWRENCE CONWAY CONCERNING STEAM GENERATOR TUBE INTEGRITY (STEAM GENERATOR DESIGN)

Q.1. State your name, address and present occupation.

A.1. My name is Lawrence Conway. My address is 1603 The Oaks Dr., Maitland, Florida 32751. My employer is Westinghouse, Steam Turbine Generator Division and I am employed as an Advisory Engineer.

Q.2. Please state your educational background.

A.2. I graduated from high school in 1952 and was then employed as an apprentice engineer at C.A. Parsons and Company Ltd., England. For the years 1952-56 I co-oped between Parsons and Rutherford College of Technology where I studied Mechanical Engineering, graduating with a Diploma in Mechanical Engineering in May 1956.

In October 1956, I entered the University of Durham, England and graduated in June 1959 with a First Class Honors Degree in Mechanical Engineering. I immediately re-enrolled at the University of Durham for post-graduate studies and graduated in December 1962 with a Ph.D. in Mechanical Engineering. During the course of my education, I was awarded the following academic honors - - Weighton Medal, Stephenson Medal, Doxford Scholarship, and the Doxford Prize.

Q.3. Please state your work experience.

A.3. The years December 1962 through December 1963 were occupied by teaching and performing mechanical engineering research at various educational institutions. In January 1964, I was employed by Brown Engineering Company, Huntsville, Alabama as a Mechanical Engineer, working on heat exchangers associated with Aero-space products. In the period from January through April 1967, I was successively promoted to instrumentation Systems Department Manager.

In April 1967, I accepted employment by Westinghouse at the Advanced Reactors Division as a Fellow Engineer. For the period up to August 1968, I

performed heat transfer and safety and systems analyses on advanced nuclear power systems, predominately liquid-metal breeder concepts.

In August 1968, I transferred to Westinghouse Tampa Steam Generator facility as a Fellow Engineer. Initially, I performed heat transfer analyses of Westinghouse steam generators but in August 1969 I transferred disciplines to stress analysis and design. The tasks generally were to lay out the geometry of a steam generator, size the parts, then draft a stress report in accordance with the requirements of the ASME Boiler and Pressure Vessel Code, Section III.

In 1972, I was promoted to Manager of Stress Analysis and supervised the efforts of 10 to 20 mechanical engineers performing analyses of all steam generator models.

In 1977, I became Manager of Engineering Mechanics, which embraced all of fluids, heat transfer, stress analysis, and testing required for Westinghouse steam generators. In 1979, I became Manager of Heat Exchanger Engineering and I supervised the design, drafting, analysis and testing of all Tampa heat

transfer products. The personnel involved numbered 50 to 60, depending upon factory loading.

In September 1982, I transferred to the Steam Turbine Generation Division as an Advisory Engineer.

In sum, I have over 14 years of experience with respect to the design and fabrication of Westinghouse Steam Generators.

Q.4. What is the purpose of your testimony?

A.4. My testimony is to explain the function of steam generators, and the design evolutions since the initial models were first used in Westinghouse nuclear power plants. In particular, I wish to place emphasis on the actions taken to enhance resistance to tube degradation especially with respect to the steam generator designs at Byron Station.

Q.5. Please describe the function of a steam generator in relation to the balance of a nuclear steam supply system.

A.5. Nuclear fuel releases heat during the fissioning process which must be converted to a form useful for driving a steam turbine. This is accomplished by

the nuclear fuel heating primary water to a high temperature and pressure. The primary water then utilizes a heat exchanger to transfer the heat in the primary water to convert the secondary water to steam which drives the turbine in a conventional manner. The common name in the nuclear industry for the heat exchanger which transfers heat from the primary water to secondary boiling water is a steam generator.

Q.6. What types of steam generators does Westinghouse manufacture?

A.6. Westinghouse manufactures two general types of steam generators, specifically those of the feedring design and those of the preheat design. The feedring type was historically the first and simplest of steam generators, but several decades ago, conventional fossil-fueled units increased the plant thermal efficiency by introducing a preheater. For similar reasons, the nuclear power industry introduced the concept of a preheater after first developing the feedring design.

Q.7. Please describe the salient features of a feedring type steam generator.

A.7. A typical feedring steam generator is depicted in Figure 1. It consists of several thousand heat transfer tubes (1) which are bent into an inverted U-shape. The open ends of the U-tubes are supported from a large circular perforated plate called a tubesheet (16). The hot, high pressure primary water (5) flows through the inside of the tubes rising from the hot leg side (2) of the tubesheet and exiting from the diametrically opposite cold leg side (6) of the tubesheet. A partition below the tubesheet called a divider plate (17), separates the hot and cold primary water. Cold feedwater (secondary water) enters the steam generator above the tubesheet and flows around the outside of the tubes (3), picking up heat, and exits from the top of the tube bundle as wet steam (12). The wet steam is then dried for turbine use (7) in two stages: swirl vanes (11) and then demisters (13). The water separated from both driers is returned to the outside of the tube bundle (14) as recirculation. The entire assembly of tubesheet and tube bundle is contained within a cylindrical pressure vessel which is the outside shell (4) of the steam generator.

To assure that all of the tubing is most effectively utilized to transfer heat, the feedwater is directed

to enter the bundle just above the tube sheet. This fluid routing is accomplished by surrounding the bundle, inside the shell, by a thin cylinder called a wrapper (10). Since the tubes are generally about 30 feet in length from the tubesheet to the top of the U-bends, tube support plates (15) through which the tubes pass are installed at vertically spaced intervals.

The salient features of this type is that the feedwater (8) is introduced high in the vessel, just above the U-bends of the tubes where it mixes with the water separated from the wet steam (12). A perforated torus (9) is attached to the interior of the feedwater nozzles so as to uniformly distribute the feedwater around the periphery of the wrapper. All of the Westinghouse feedring steam generators are visually similar, differing significantly only in the amount of surface area of the tubing. The early Westinghouse steam generators had 27,000 square feet of tubing area, thus, they were designated the Model 27 series. As power requirements increased, the surface area was increased correspondingly. This led to the development of the Models 33, 44 and 51 series of steam generator with

33,000, 44,000 and 51,000 square feet of tubing surface area, respectively.

Q.8. How do the design features of the preheat type of steam generator differ from the feedring type?

A.8. To accomplish the increase in thermal efficiency in the preheat design, Figure 2, the feedwater is introduced directly to the cold leg side of the tubes (8). This necessitated locating the feedwater nozzle at a position just above the tubesheet (16). The other physical features of a preheat steam generator design are similar to those of a feedring type (i.e., tubes, wrapper, tube support plates, driers, etc.). Since the various Westinghouse preheat model designs do not correspond to the amount of tube surface area, the designations of these various designs were changed to an alpha-numeric systems, e.g., Models D2, D3, D4 and D5.

Q.9. What are the standards used in the Westinghouse design?

A.9. Two standards are used in the design of Westinghouse steam generators: Tubular Exchanger Manufacturers Association (TEMA) and the Boiler and Pressure Vessel (B&PV) Code of the American Society of Mechanical Engineers. The TEMA standards are mainly

function related and contain many drawings of heat exchangers similar to the Westinghouse designs. The B&PV Code mainly concerns itself with the physical integrity of vessels. The Westinghouse designs are always in accordance with the Code amendment(s) in effect at the time of design and it is utilized in both the selection of material and the thickness of parts used.

Q.10. Do steam generator designs incorporate measures to avoid or minimize potential tube degradation?

A.10. Yes, there are three means that we mechanical designers can use to deal with potential steam generator tube degradation. These are: (1) material selection, (2) design configuration to minimize areas for chemical concentration, and (3) level of mechanical stress.

Q.11. What tubing and tube support plate materials were selected for Westinghouse steam generator designs?

A.11. The tubing material selected for the Westinghouse steam generators was chosen to be suitable for the temperature, stress and chemical environment within a steam generator under normal and design basis accidents. The specific alloy selected was Inconel 600. Later field feedback indicated that even

greater corrosion resistance would be desirable and this resulted in the selection of thermally-treated Inconel 600.

The tube support plate material initially selected was a good quality state of the art carbon steel. Later field feedback indicated that increased chemical resistance tube support plate material would make it very much less likely for denting of the tubes to occur. As a consequence, the conventional carbon steel was upgraded to stainless steel in later designs.

Q.12. What mechanical design features were introduced to minimize potentially adverse chemical concentrations in Westinghouse steam generator designs?

A.12. Chemical concentrations occur as a result of either sludge buildup or hideout in crevices within the steam generator. Several design changes were introduced by Westinghouse to address these concerns.

Sludge buildup is minimized by recirculating the secondary water at a fast rate to scavenge as many areas within the steam generator as possible. The flow rate was increased by streamlining the

recirculation flow paths. This objective was accomplished by eliminating the downcomer resistance plate. Moreover, to enhance streaming the flow, a flow distribution baffle (Item 18 in Figures 1 and 2) was installed close to the top of the tubesheet and to block the divider lane between the tubes at the tubesheet. Similarly, the height of the wrapper above the tubesheet was adjusted to maximize this streaming effect. These design changes directed the flow into desirable paths which reduced sludge precipitation.

Sludge precipitation was further minimized by increasing the chemical blowdown from the steam generator and modifying the abstraction ports. In addition, the hole geometry in the support plates were changed from a circular geometry (Figure 3) to a four lobed geometry (quatrefoil, Figure 4). This design change served the dual purpose of (1) improving flow rate circulation pathways in the entire steam generator, and (ii) reducing hideout by permitting the secondary water to intimately scavenge the area between the support plate and tubing.

Finally, the potential for hideout in the crevice between the tube and the tubesheet hole was eliminated by expanding the tube within the tubesheet hole. This design change essentially removed the crevice.

Q.13. What measures were taken to reduce tubing stresses in the Westinghouse steam generator designs?

A.13. The basic U-tube design of a Westinghouse steam generator is a very compliant structure (i.e. it is relatively free to expand with increasing temperature) and, therefore, inherently lightly stressed. Also, the widest tube support plate spacing which is functionally acceptable was selected to restrict interference with the free motion of the tubes due to temperature effects.

Conventionally, tubes had been sealed in the tube sheet holes by mechanically expanding the tube with mechanical rollers. Recently, Westinghouse had developed an expansion technique which utilizes a fluid to uniformally expand the tube in the hole and simultaneously give a very smooth transition from the expanded to unexpanded section of the tube. This results in a significant reduction in stress.

Another measure which has been taken to reduce tube stress involved the holes in the flow distribution baffle. The proximity of this plate to the tubesheet requires careful design to reduce interference stresses resulting from differences in temperature between the flow distribution baffle and tubesheet. The first change made was to slot the tube holes radially to allow uninhibited tube motion. However, subsequent tests of various hole sizes, baffle height and other fluidic variables showed that stresses could be even further reduced. This was accomplished by having different size holes in the baffle, with the size of the hole successively increasing in the direction away from the tube lane.

Tube degradation had occurred at the top of small radius U-bends area. This was caused by deformation of the slotted flow holes in the top tube support plate. This phenomenon was eliminated by changing the flow hole geometry to a more rigid circular hole pattern.

Q.14. What steam generator designs are installed at the Byron Site?

A.14. Both Byron Unit 1 and Byron Unit 2 have preheat steam generators which are functionally identical.

The specific models are D4 at Byron Unit 1 and D5 at Byron Unit 2. The differences between these designs occurred as part of the normal evolution over time of steam generator designs.

Q.15. Do the S.G.'s installed at the Byron Station embody the mechanical design features you have described for minimizing the potential for tube degradation?

A.15. Yes, many design improvements have been incorporated in the Byron Station steam generators to protect against potential tube degradation.

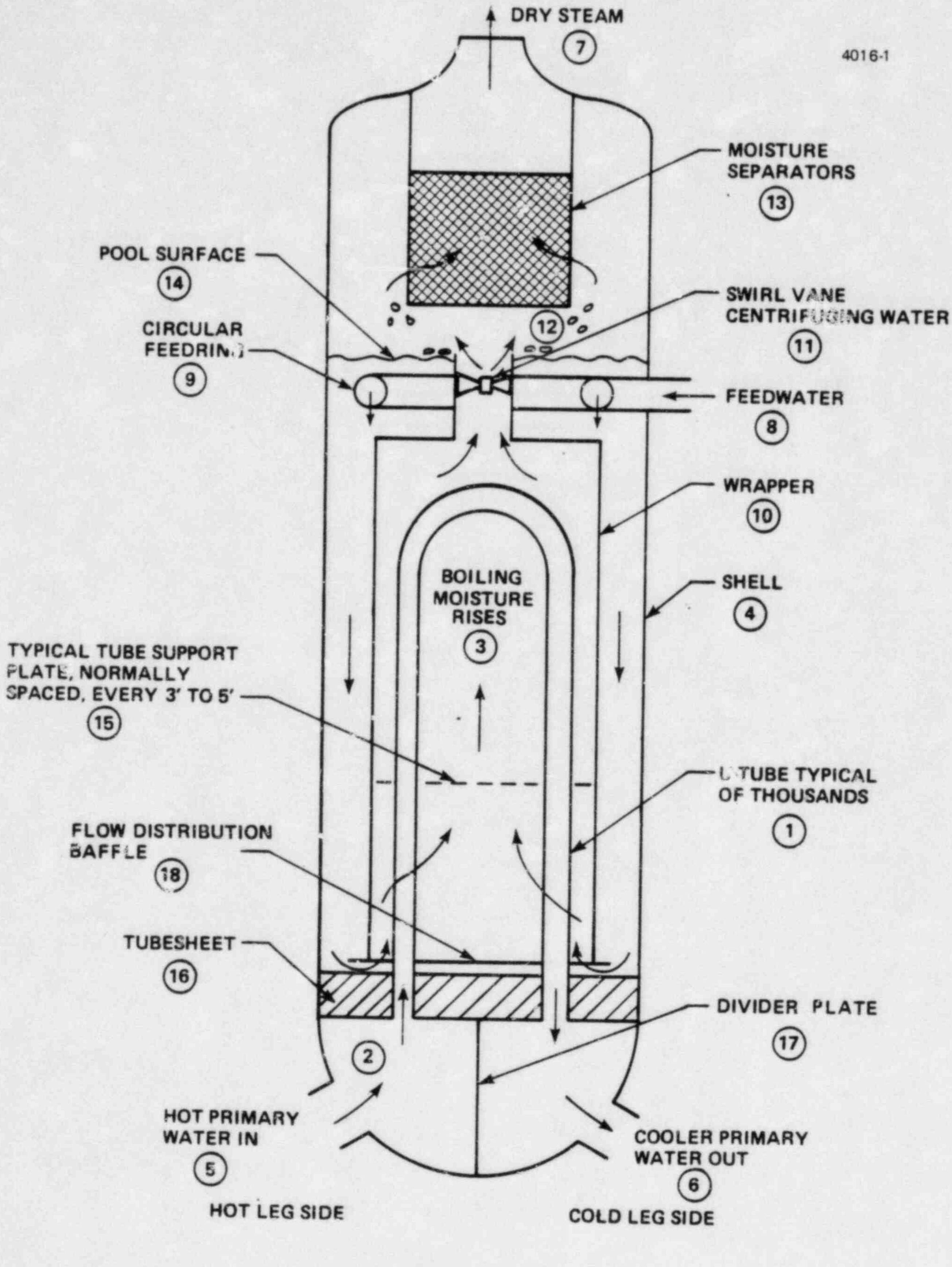
Inconel 600 was chosen for the steam generator tube material as being the most suitable for the temperatures, chemical environment, and design basis accident conditions present witin a steam generator. To minimize chemical concentration areas (such as at the tube sheet and between the tube and tube support plate), recirculation rates were optimized, the ports in the blowdown pipe were modified, and the tubes within the tubesheet hole were expanded to eliminate the crevices at the tubesheet. To minimize tube stresses, in addition to low stresses being inherent in a U-shape tube design, the widest spacing between tube support plates which is functionally acceptable was selected, the holes in the

flow distribution baffle plates and in the top tube support plate were modified.

In addition, the design of the Model D5 in Unit 2 has been enhanced by (1) utilizing stainless steel as the material for the tube support plates and baffles, (2) changing the shape of the holes in the tube support plates from circular to a quatrefoil shape, (3) expanding the tubes within the tube sheet by means of a hydraulic device in lieu of mechanical rollers, (4) the Inconel 600 tubes were thermally treated, and (5) the holes in the flow distribution baffles were changed from slotted to a circular shape.

Q.16. Do you have an opinion concerning the design adequacy of the Byron Station steam generators from the standpoint of minimizing tube degradation?

A.16. Yes. I consider the steam generators in both units of Byron Station to embody the very best design features from the perspective of minimizing tube degradation as well as overall performance and safety.



4016-1
DRY STEAM
7
MOISTURE
SEPARATORS
13
POOL SURFACE
14
SWIRL VANE
CENTRIFUGING WATER
11
12
CIRCULAR
FEEDRING
9
FEEDWATER
8
WRAPPER
10
BOILING
MOISTURE
RISES
3
SHELL
4
TYPICAL TUBE SUPPORT
PLATE, NORMALLY
SPACED, EVERY 3' TO 5'
15
TUBE TYPICAL
OF THOUSANDS
1
FLOW DISTRIBUTION
BAFFLE
18
TUBESHEET
16
DIVIDER PLATE
17
2
HOT PRIMARY
WATER IN
5
COOLER PRIMARY
WATER OUT
6
HOT LEG SIDE
COLD LEG SIDE

Figure 1.

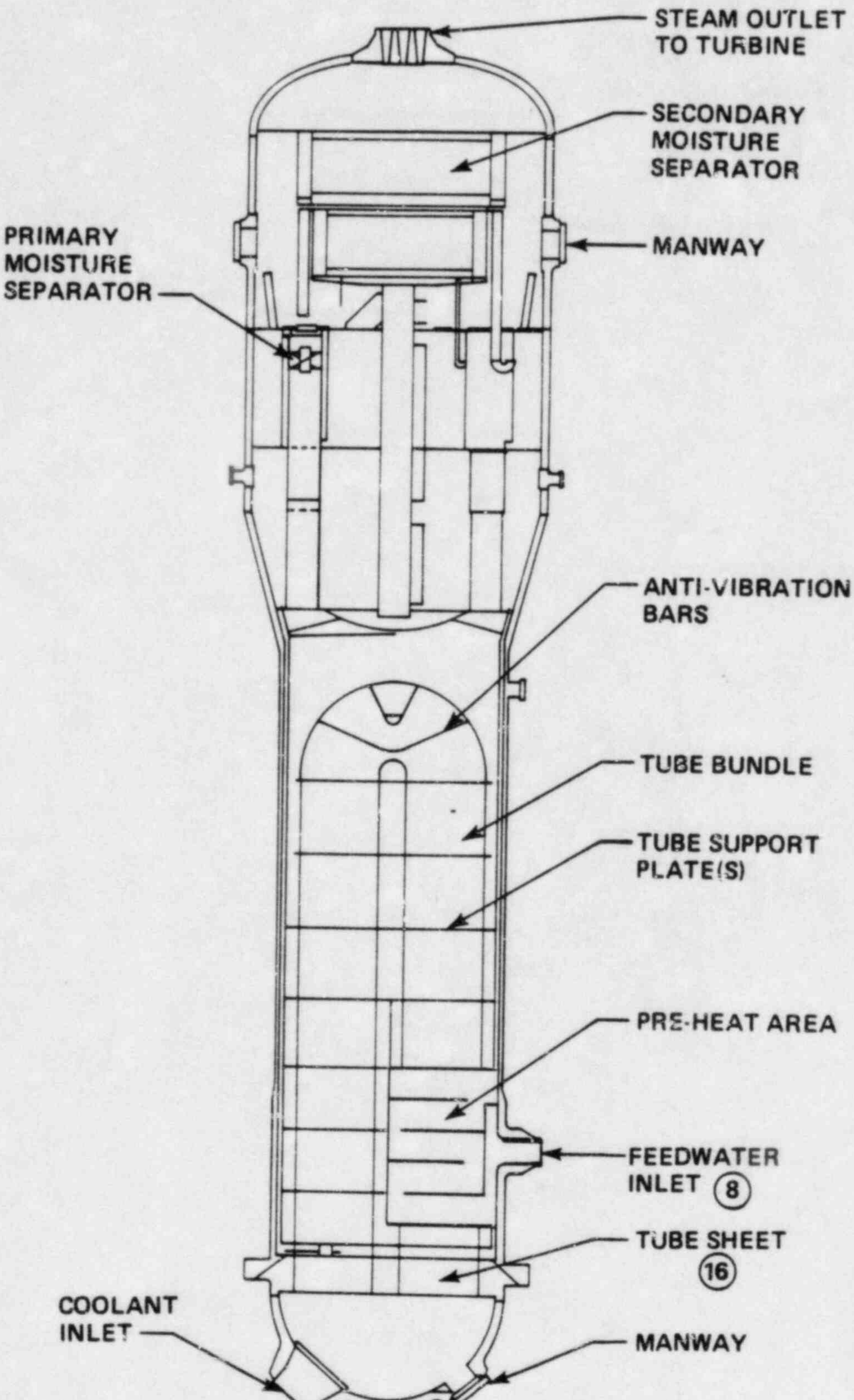


Figure 2. Model D4 Steam Generator

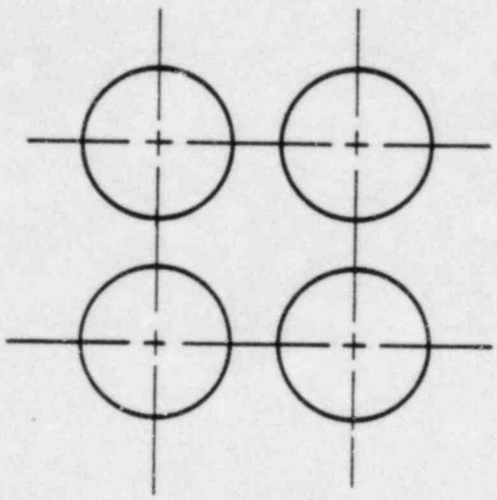


Figure 3. Model D4 Round Holes in Tube Support Plates

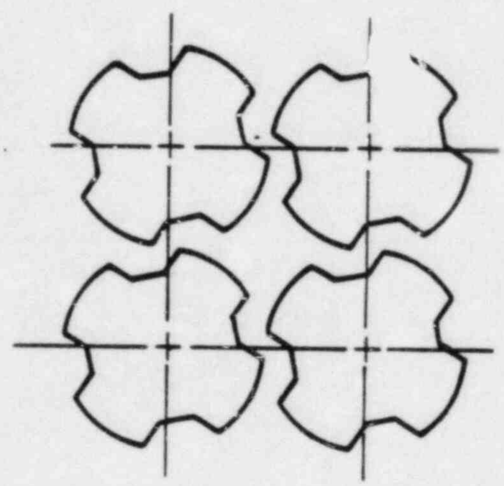
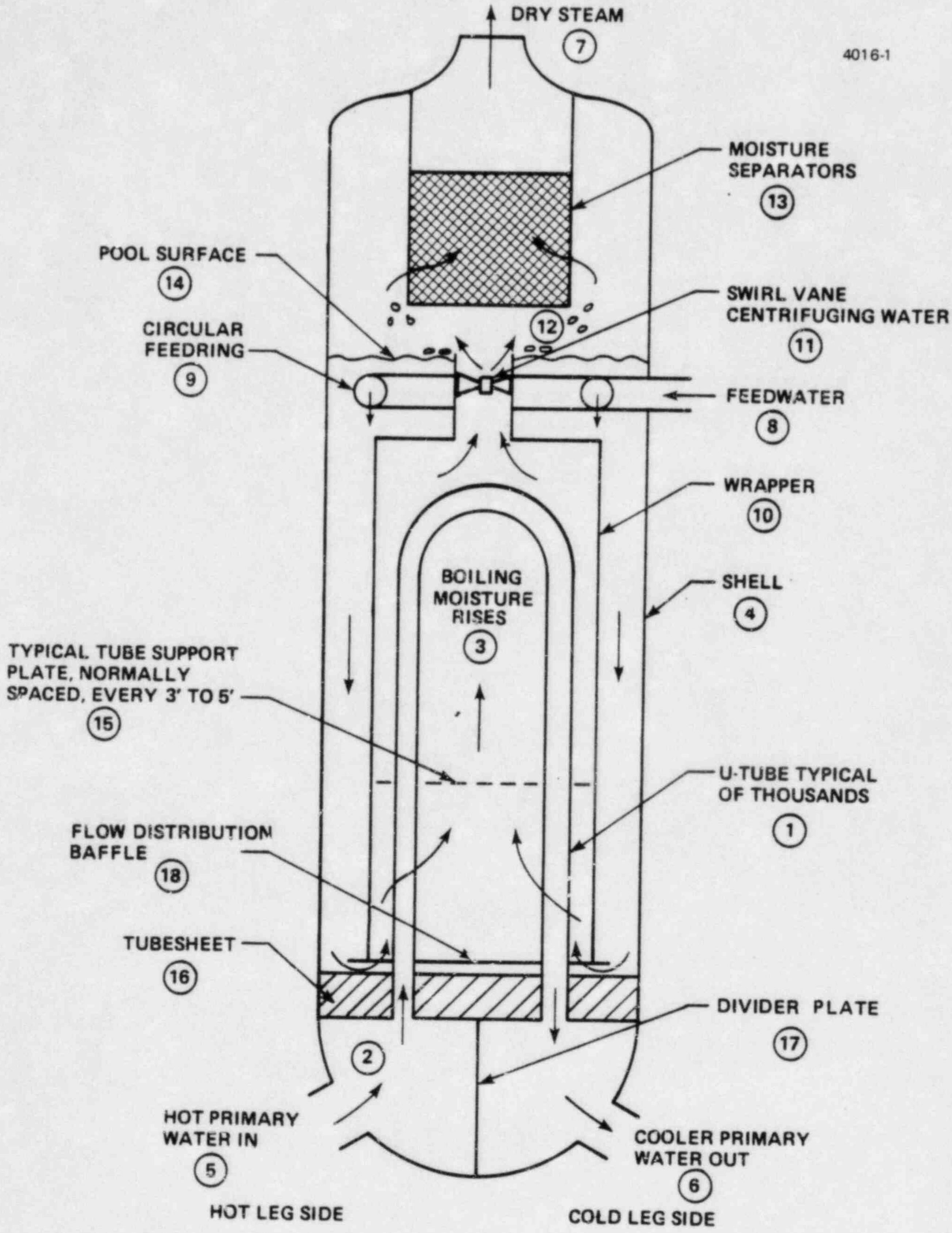


Figure 4. Model D5 Quatrefoil Hole in Tube Support Plates


4016-1
DRY STEAM
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16
DIVIDER PLATE
17
2
HOT PRIMARY
WATER IN
5
COOLER PRIMARY
WATER OUT
6
HOT LEG SIDE
COLD LEG SIDE

Figure 1.

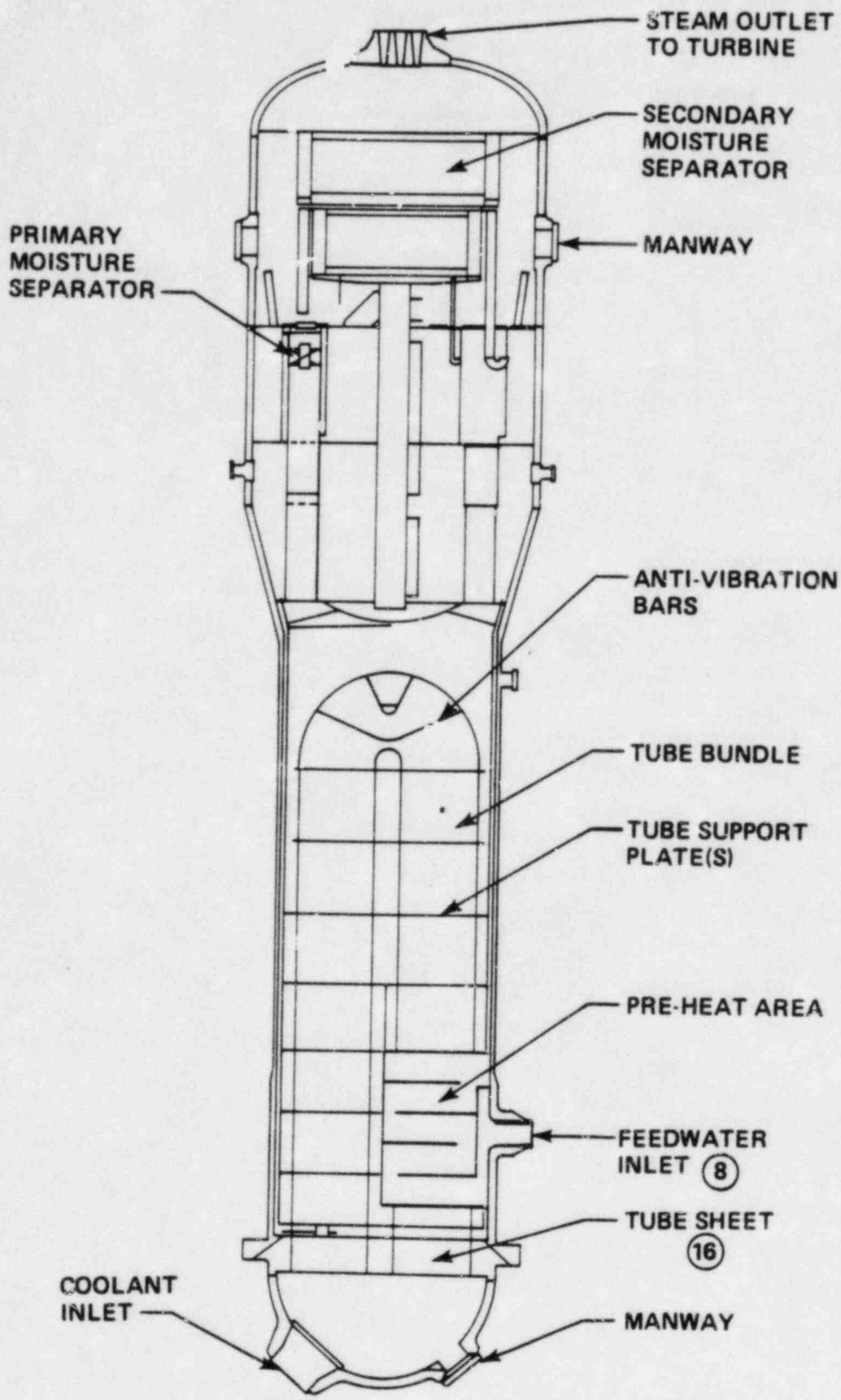

Figure 2. Model D4 Steam Generator

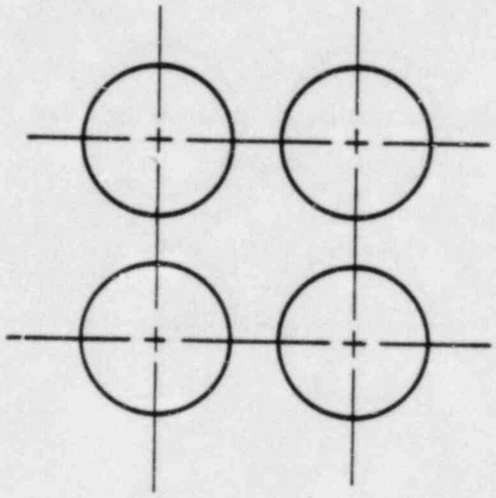

Figure 3. Model D4 Round Holes in Tube Support Plates

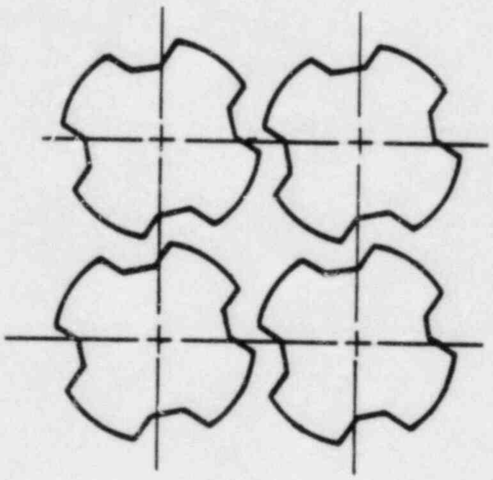

Figure 4. Model D5 Quatrefoil Hole in Tube Support Plates