Date: 2/15/83

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
COMMONWEALTH EDISON COMPANY	)	Docket Nos. STN 50-454 OL
	)	STN 50-455 OL
(Byron Nuclear Power Station,	)	
Units 1 and 2)	)	

SUMMARY OF TESTIMONY OF
ROBERT W. CARLSON

Robert W. Carlson is a Principal Engineer with Westinghouse Electric Corporation. He is an expert in the bubble collapse waterhammer phenomenom. His testimony addresses DAARE/SAFE Contention 9a as that contention concerns the possibility of the occurrence of a waterhammer event at Byron Station similar to the one that occurred at the KRSKO plant in Yugoslavia.

Mr. Carlson generally describes the steam generator designs of the KRSKO plant and the Byron Station. He also describes the KRSKO waterhammer event and the conditions which are believed to have caused it. Mr. Carlson explains how the plant operating condition affects the likelihood of conditions which can lead to a KRSKO-type waterhammer event. Mr. Carlson explains the damage which occurred at the KRSKO plant due to the waterhammer event and the corrective action taken there.

Mr. Carlson explains the present and proposed check valve arrangement at the Byron Station. He concludes that the proposed check valve arrangement is consistent with Westinghouse's recommendations.

Mr. Carlson relates the recommendations made by Westinghouse to Commonwealth Edison Company for prevention of a KRSKO-type waterhammer event. Mr. Carlson concludes that if Commonwealth Edison Company follows these recommendations, the likelihood of the occurrence of a KRSKO-type waterhammer event at Byron Station is reduced to an acceptable level.

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TESTIMONY OF ROBERT W. CARLSON

Q1: Please state your name, present position, and present occupation.

A1: My name is Robert W. Carlson. I work for the Westinghouse Electric Corporation as a Principal Engineer in the Balance of Plant Systems Design Group of the Nuclear Technology Division.

Q2: Could you please describe your educational and professional background?

A2: I received a Mechanical Engineering degree from Stevens Institute of Technology in 1953 and a Master of Science degree in Nuclear Engineering from Massachusetts 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.

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 with the Atomic Power Division. I joined the Westinghouse PWR 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.

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 phenomenon as it occurred in horizontal pipe sections. In 1977, I participated in a test program to investigate bubble collapse waterhammer in preheat steam generator designs including the Byron Station 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.

I meet, on behalf of Westinghouse, with utility customers and their architect-engineers to provide assistance in the design and operation of the plant modifications recommended by Westinghouse to minimize the likelihood of of bubble collapse waterhammer. As part of this responsibility, I have reviewed the available information on the waterhammer event which occurred in the feedwater bypass system at the KRSKO plant.

Q3: What is the purpose of your testimony?

A3: The purpose of my testimony is to address DAARE/SAFE Contention 9a as that contention concerns the possibility of the occurrence of a waterhammer event at the Byron Station similar to the one that occurred at the KRSKO plant.

Q4: Please describe the waterhammer phenomenon.

A4: In general, there are two forms of waterhammer, classical and bubble collapse. In both cases, a change in water velocity leads to a change in pressure because of the inertia of the water. The two forms differ with respect to the mechanisms by which the change in velocity is brought about. As an example of classical waterhammer, consider a pipe with water flowing inside. If a valve at the downstream end of 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 back and forth in the pipe until it dissipates due to friction. Bubble collapse waterhammer refers to a 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, nothing will happen. However, if the slugs contain cold water which comes into contact with the steam, the steam will be condensed 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.

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.

Q5: What are the potential effects of waterhammer?

A5: Waterhammer, whether classical or bubble collapse, will result in a change in water pressure. The change in pressure has the potential for damaging components of the piping system. The pressure change, if large enough, may result in pipe deformation or, in an extreme case, rupture. It may also result in valve damage, for example, damage to valve packing and gaskets. The change in water pressure inside the system is accompanied by forces transmitted to the pipe supports. As a consequence, pipe hangers may also be damaged.

Q6: Please generally describe the steam generator designs of the KRSKO plant and the Byron Station.

A6: Before discussing steam generator features, the terms primary side and secondary side should be explained. The primary side and secondary side of the steam generator refer to the fluid volumes inside and outside the steam generator tubes, respectively. The steam generator is a component in the primary loop which includes the reactor. The primary side water carries thermal energy from the reactor core to the steam generator. The hot primary water is directed into the inlet half of the inverted U shaped tube bundle. The first half of the bundle where the primary water flows upward is referred to as the hot leg side. The second half where the water flows downward is referred to as the cold leg side because the primary water is somewhat cooler having given up some of its thermal energy.

The secondary side refers to the volume outside the tube bundle and inside the steam generator vessel.

During normal operation, the lower part of the vessel contains water and the upper part steam. The fact that both steam and water are present on the secondary side accounts for bubble collapse waterhammer being a design consideration.

The Byron plant and the KRSKO plant both have steam generators of the preheat type referred to by Westinghouse as the Model D. Within the Model D classification, there are two subtypes: the split flow type (D2 and D3) and the counterflow type (D4 and D5). The Byron No. 1 unit and the KRSKO plant both have Model D4 steam generators while Byron No. 2 unit has Model D5 steam generators. The counterflow type steam generator (Models D4 and D5) is shown in Figure 1. For purposes of this discussion, the difference in design between Models D4 and D5 steam generators is not relevant.

The overall height of the Model D steam generator is approximately 68 feet. The Model D steam generators have two connections for introducing feedwater. The 16 inch diameter main nozzle is located in the lower shell approximately 13 feet from the bottom of the vessel. The 6 inch diameter auxiliary nozzle is located in the upper shell approximately 45 feet from the bottom of the vessel.

The preheater section is a baffled region of the tube bundle inside the steam generator located on the cold leg side close to the tube sheet. The feedwater enters the preheater through the main 16 inch nozzle in the lower shell. The purpose of the preheater is to efficiently transfer heat from the cold leg side primary fluid to the incoming feedwater.

Q7: What is the purpose of the Feedwater Bypass System?

A7: It was recognized that the presence of steam bubbles and cold water in the preheater section could cause a bubble collapse waterhammer. Westinghouse undertook a test program in 1977 to investigate and define the effects of this type of waterhammer in the preheater region. As a consequence of this testing, the Feedwater Bypass System was developed and implemented for the preheat type steam generators. The Feedwater Bypass System is designed to automatically prevent the introduction of cold water into the preheater section. In those circumstances where it is necessary to introduce cold water into the steam generator, the Feedwater Bypass System operates to direct the cold water to the upper auxiliary nozzle. The basics of the Feedwater Bypass System are shown in Figure 2. It consists of a 6 inch diameter line which connects the main feedwater line to the auxiliary nozzle.

Q8: What is the purpose of the Auxiliary Feedwater System?

A8: As indicated on Figure 2, the Auxiliary Feedwater System connects to the bypass line. The Auxiliary Feedwater System provides feedwater to the steam generator through the bypass piping and the auxiliary nozzle in the event of a loss of heat sink accident, such as a feedwater pipe rupture.

Q9: Please describe the waterhammer event that occurred at the KRSKO plant.

A9: A bubble collapse waterhammer occurred in the Feedwater Bypass System of the KRSKO Nuclear Power Plant during Hot Functional Testing of the Auxiliary Feedwater System pumps in July, 1981. Steam apparently pushed back into the bypass line and then into the Auxiliary Feedwater System piping. Subsequently, the Auxiliary Feedwater System pumps were started introducing cold water into the piping. Thus, the two elements needed for a waterhammer event were present, i.e., a volume of steam and cold water. The first indications that an unusual event had occurred were the discoveries in early August, 1981 of damage to the feedwater bypass piping inside the containment and of blistering paint on the Auxiliary Feedwater System piping.

Q10: What conditions are believed to have caused the KRSKO waterhammer event?

A10: For steam to push back into the bypass piping, it was necessary that the check valves which are provided to prevent reverse flow in the Auxiliary Feedwater System were leaking and that the steam generator water level was below the auxiliary nozzle internal extension. 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. If the water is kept at the normal operating level, steam cannot enter the internal extension and thus cannot enter the bypass piping. At KRSKO, the water level must have been below the discharge end of the auxiliary nozzle internal extension since steam did enter the bypass piping.

In addition to the below-normal water level, it was necessary for the check valves associated with each of the motor driven auxiliary feedwater pumps to have leaked. The extent of the backleakage of steam and/or hot water was indicated by the blistered paint on the Auxiliary Feedwater System piping which was discovered as far back as the motor driven pumps.

With steam present in the bypass line the motor driven pumps were started as part of Hot Functional Testing, introducing cold water into the bypass piping. The water rapidly condensed the steam resulting in a waterhammer.

Q11: Assuming a failure of the check valves which are provided to prevent reverse flow and assuming the steam generator water level falls below the auxiliary nozzle internal extension, under what plant operating conditions can steam backleakage into the bypass line occur?

A11: Assuming a failure of the check valves and the low water level, backleakage during power operation is very unlikely since between 0 and 100 percent power a continuous flow is provided through the steam generator auxiliary nozzle which effectively prevents the backflow of steam from the steam generator. Above approximately 20 percent power, when the feedwater flow is supplied through the main nozzle, a tempering flow which is equivalent to one to two percent of the main feedwater flow at 100 percent power is maintained through the auxiliary nozzle. The purpose of the tempering flow is to maintain the auxiliary nozzle at feedwater temperature thus reducing the induced thermal stresses when feedwater is transferred from the main nozzle to the auxiliary nozzle, for example, during plant unloading. However, the tempering flow also effecively prevents steam backleakage and consequently tne occurrence of waterhammer.

During the normal operations of heatup, cooldown and hot standby, feedwater is supplied only through the auxiliary nozzle. However, only relatively small amounts of feedwater are required, not enough to always permit a continuous flow so that the opportunity for steam backleakage does exist if the check valves fail and the steam generator water level falls below the auxiliary nozzle internal extension. However, the plant operator is instructed to feed continuously rather than intermittently as much as possible. This practice reduces the likelihood of steam backleakage and therefore waterhammer.

Q12: What damage resulted at the KRSKO Plant as a result of the waterhammer event?

A12: To aid this discussion, two isometric sketches of the feedwater bypass piping at KRSKO are presented in Figures 3 and 4. Figure 3 shows the bypass piping inside containment from the auxiliary nozzle to the containment vessel penetration. Figure 4 shows the section of bypass piping from the containment penetration to the point where the Auxiliary Feedwater System connects.

Inside the containment building, hanger embedment plates were moved, hanger bolts were loosened and pipe clamps were loosened and moved. The locations of affected hangers are identified in Figure 3 by the numbers in ovals. Also inside containment, some change in the location of bypass piping was observed. Also, a bulge was discovered on the upper surface of the bypass piping near the secondary shield wall. The bulged region was approximately six to eight inches long and increased the pipe diameter by approximately one-quarter inch.

Outside of the containment building, there was negligible pipe movement. The paint on the auxiliary feedwater piping was blistered back to the motor driven auxiliary feedwater system pumps.

Despite the damage, the design functions of the Auxiliary Feedwater System and the Feedwater Bypass Systems were not adversely affected.

Q13: What corrective actions have been taken at the KRSKO plant in terms of redesign, repair, operator instruction or procedures for avoidance of waterhammer in the future?

A13: The principal modification was to install two temperature sensors on the bypass piping inside containment close to the auxiliary nozzle of each steam generator. The temperature sensors are connected to the plant's DATA-SCAN Temperature Monitoring System which allows for printing out the temperature values in the control room on request. The system activates an alarm if the temperature values exceed predetermined set-points. Recommended operating guidelines have been provided to KRSKO for utilizing the temperature data.

With respect to KRSKO plant repair, the section of bypass piping containing the bulge, was replaced. Also the hanger damage was repaired. To reduce the likelihood of backleakage, the Auxiliary Feedwater System check valves, which were determined to have been leaking, were refurbished.

With respect to plant operation, Westinghouse has instructed KRSKO to maintain the steam generator water level above the top of the auxiliary feedwater discharge pipe inside the steam generator as much as possible. 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.

In the eventuality that the presence of steam is suspected in the bypass line of one or more loop, based on temperature data and water level status and history, the recommended course of action is to slowly refill one loop at a time with the Auxiliary Feedwater System. An analytical study by the Westinghouse R & D Center shows that the safe refilling flow rate is in the range of 15 to 123 gpm per steam generator. To be conservative, Westinghouse has recommended the value of 15 gpm or as close to this as can be provided.

Q14: Are you familiar with the present and proposed check valve arrangements in the Feedwater Bypass and Auxiliary

Feedwater Systems at the Byron Station?

A14: Yes.

Q15: Please describe those arrangements in light of their impact on the potential for steam backleakage into the Auxiliary Feedwater System.

A15: Consistent with Westinghouse recommendations, there should be at least two check valves in each flow path by which backleakage into the Auxiliary Feedwater System could occur. The current Byron design includes two check valves in each flow path effective in preventing backleakage into the Auxiliary Feedwater System. One is located in the bypass line close to the auxiliary nozzle and the second in the Auxiliary Feedwater System itself. Flow that leaks past these two valves would flow through the Auxiliary Feedwater System pump miniflow lines to the condensate storage tank. The check valves in the Auxiliary Feedwater System further upstream of the miniflow lines are thus ineffective for preventing backleakage.

Based on an analysis performed by Westinghouse which considered the classical waterhammer case of feedwater line break followed by check valve closure, Westinghouse recommended that 1) the two 6 inch undamped check valves in the bypass line (which includes the previously described valve close to the auxiliary nozzle) should be replaced by slow closing check valves, or 2), the valve close to the auxiliary nozzle should be removed and the other check valve in the bypass line should be replaced with a slow closing valve. Retaining the current undamped check valve close to the auxiliary nozzle while replacing the other check valve in the bypass line with a slow closing valve is not acceptable since, depending on the location of the feedwater line break, the undamped valve may still close rapidly, possibly resulting in unacceptably high loads.

Commonwealth Edison Company elected the second option described above. However, on further consideration, it was determined that this arrangement would leave only one check valve in each flow path which would be effective in preventing steam backleakage into the the Auxiliary Feedwater System and out through the pump miniflow lines. As a consequence of this determination, a new 6 inch check valve will be installed in the discharge line of each Auxiliary Feedwater System pump. This valve would be located downstream of the pump miniflow lines and upstream of the header and branch lines which supply each of the four steam generators. This check valve arrangement is consistent with the Westinghouse recommendation since it will provide two check valves in each flow path by which backleakage into the Auxiliary Feedwater System could occur.

Q16: As a consequence of the KRSKO experience, what measures has Westinghouse recommended to Commonwealth Edison Company to avoid a similar bubble collapse waterhammer in the Feedwater Bypass System at the Byron Station?

A16: Westinghouse has made the following recommendations to avoid a KRSKO type waterhammer event:

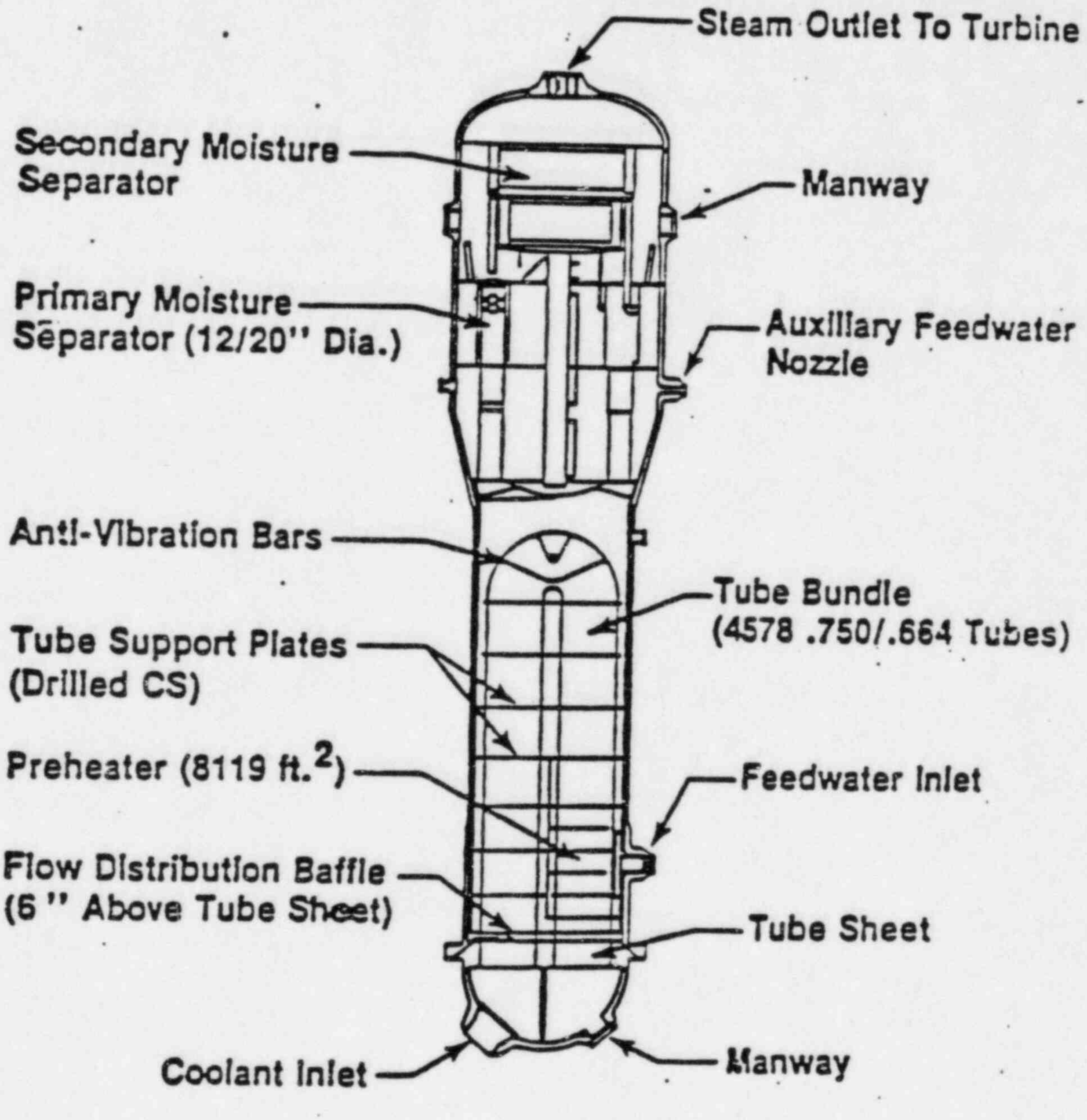
1. Temperature sensors should be installed on the bypass piping close to the auxiliary nozzle to detect backleakage of hot water or steam.
2. If backleakage is detected, the piping should be slowly refilled or the plant brought to a cold shutdown condition, depending on the circumstances. An analytical study performed by the Westinghouse R & D Center shows that the bypass piping can be slowly refilled safely. The recommended flowrate is on the order of 15 gpm.
3. The steam generator water level should be maintained above the auxiliary nozzle discharge pipe as much as possible so that if backleakage does occur, water and not steam will leak back into the pipe.
4. The Auxiliary Feedwater System check valves should be maintained to minimize backleakage.

Q17: Do you have an opinion as to whether these recommendations, if followed, would be adequate to prevent the occurrence of KRSKO type event at Byron Station?

A17: Yes.

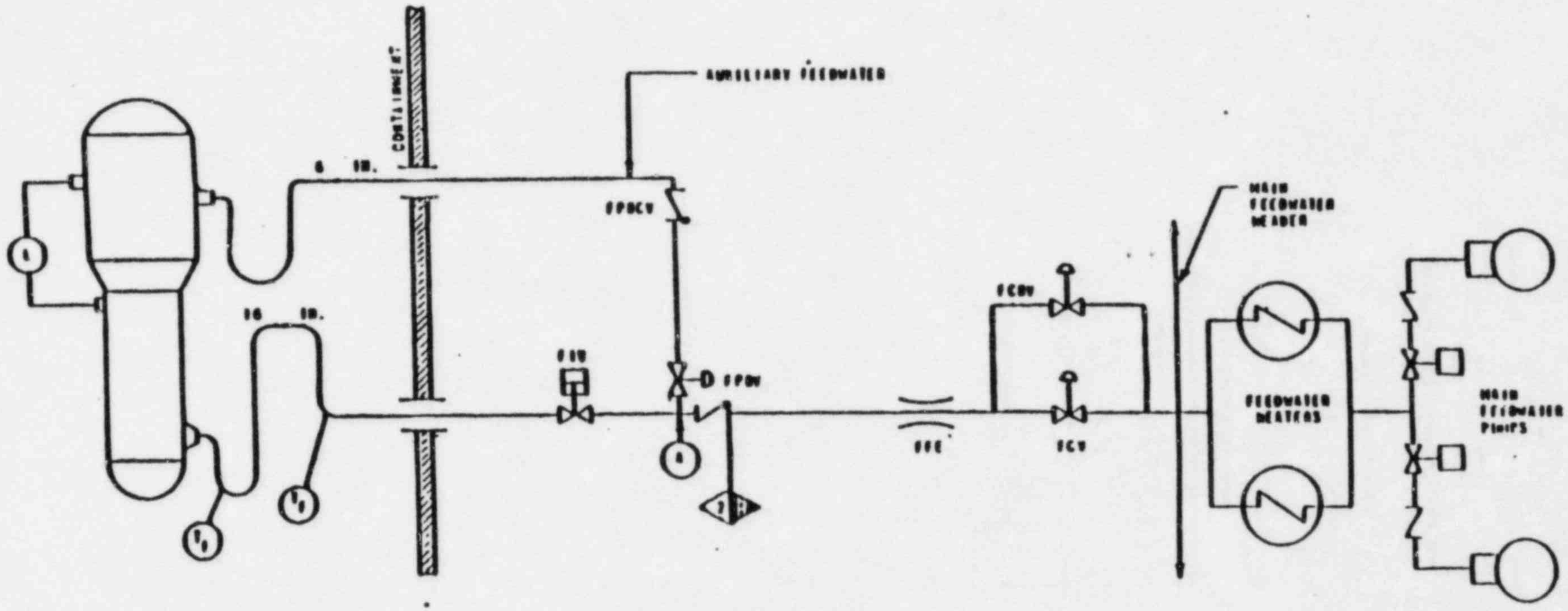
Q18: Please state that opinion.

A18: If these recommendations are adopted and implemented, and Commonwealth Edison Company installs the proposed check valves in the Auxiliary Feedwater System, the likelihood of occurrence of a KRSKO-type waterhammer event is reduced to an acceptable level.

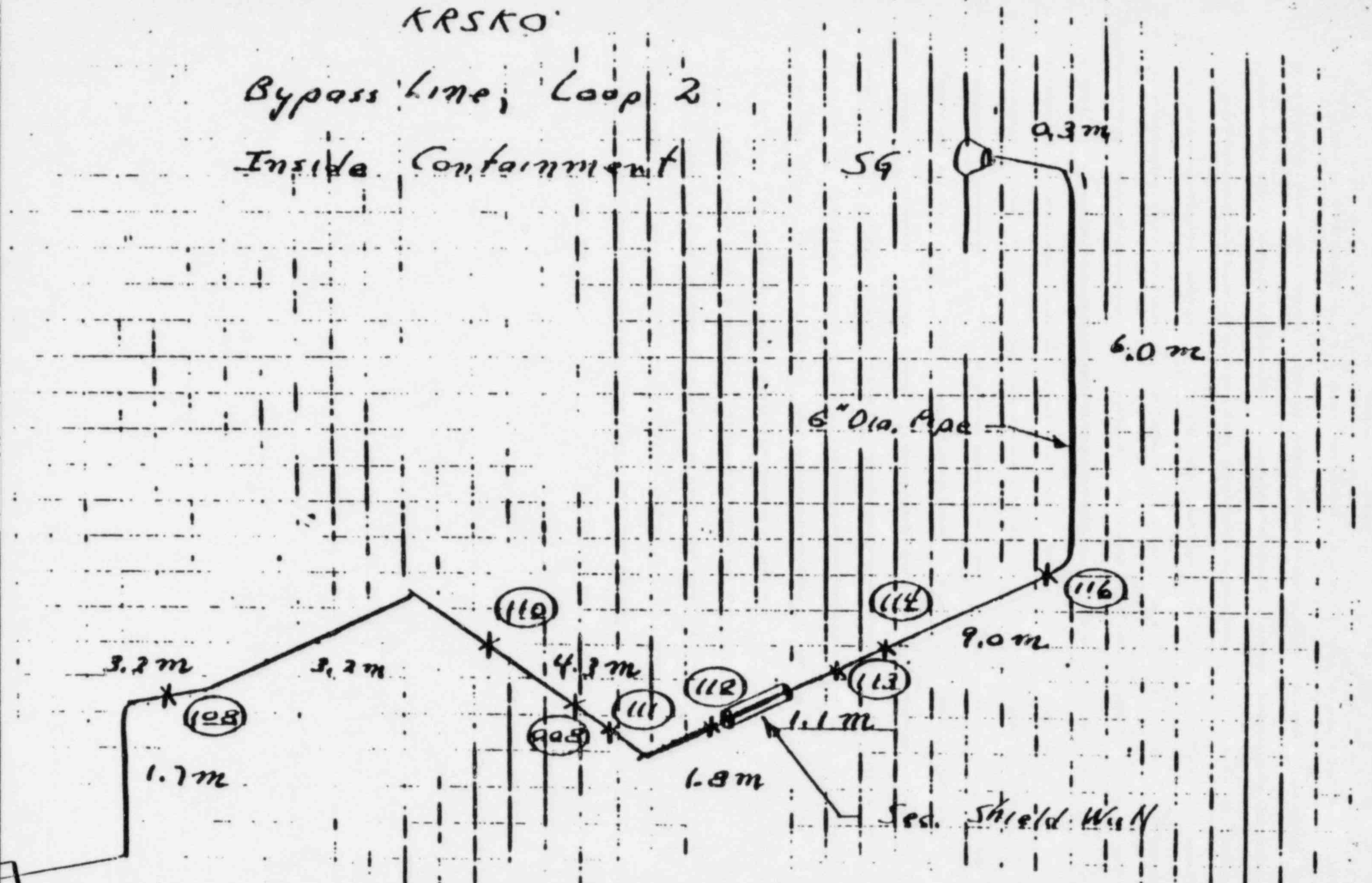


CARLSON TESTIMONY FIGURE 1

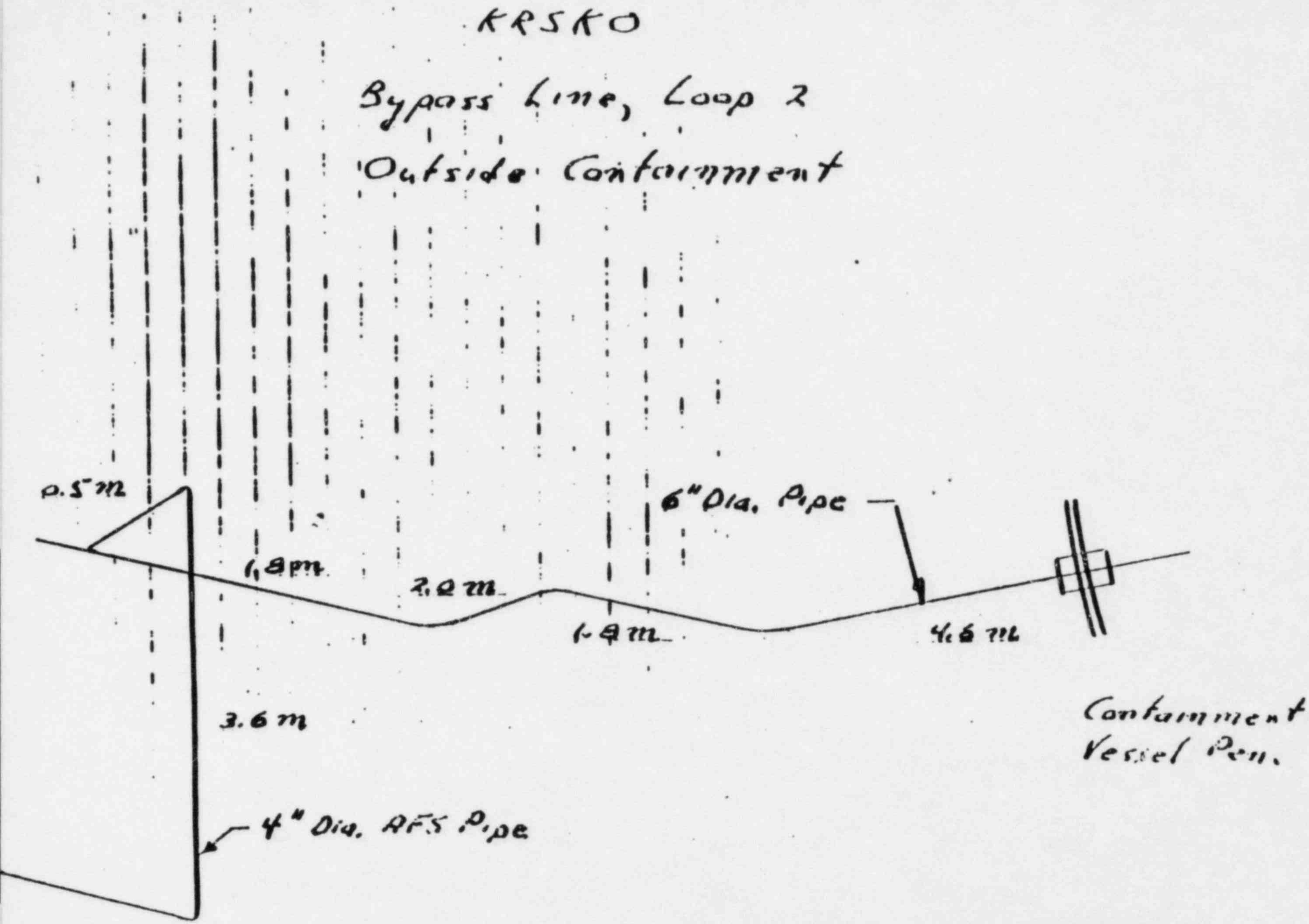
Byron Station Preheat Type Steam Generator



CARLSON TESTIMONY FIGURE 2



CARLSON TESTIMONY FIGURE 3



CARLSON TESTIMONY FIGURE 4