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MEMORANDUM FOR: Jack E. Rosenthal, Chief
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SUBJECT: TRIP REPORT – CONTROL ROD DRIVE MECHANISM NOZZLE INSPECTION AT POINT BEACH 1

A trip to the Point Beach Station was made on April 14 and 15, 1994. Dr. Vik Shah of the Idaho National Engineering Laboratory also joined me on this trip. The objective of the trip was to observe the inspection of control rod drive mechanism (CRDM) nozzles at Point Beach 1, which is the first U.S. pressurized water reactor plant to conduct such inspections. This is a 497-MWe, two-loop,Westinghouse-designed plant, which has been in commercial operation since 1970. The Point Beach licensee voluntarily inspected the CRDM nozzles; (i.e., it was not required by the U.S. Nuclear Regulatory Commission).

The CRDM nozzles are fabricated from Alloy 600, a nickel base material, and are susceptible to primary water stress corrosion cracking (PWSCC). Cracks in the CRDM nozzles due to PWSCC have been reported recently at several European reactors. The nozzles of the European reactors were also made from the same material, but using different product forms. The nozzles in French reactors and some later designed CE reactors are made from forged bars, whereas those in other plants, including most U.S. plants, are made from pipes. Although no nozzle cracks have been reported at U.S. reactors, evaluations of CRDM nozzles in U.S. reactors suggested that domestic nozzles are not inherently less susceptible to PWSCC. For this reason, three domestic plants, Point Beach 1, Oconee 2, and D. C. Cook 2, have scheduled inspections.

The CRDM nozzle inspection was conducted by the technical staff of Westinghouse, Comex, and AEA Technology during the period from April 9 - 17, 1994. The inspection employed a remotely operated robotic technique. This technique has evolved in recent years such that cracking in the nozzles can be detected, sized, and, in many cases, repaired without removal of the thermal sleeves or exposing workers to the high

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radiation environment under the reactor heads. Through field experience in the European inspections and Electric Power Research Institute (EPRI) qualification, the technology has been proven to be reliable and accurate in detection, sizing, and evaluation of nozzle cracking. The inspection was performed using a multi-frequency eddy current method in the absolute mode to detect any internal surface defect. If any defect is detected, ultrasonic examination will be performed to size the defect. Figure 1 shows a picture of the vessel head from below and the robotic equipment developed by the consortium of Westinghouse, Comex, and AEA Technology for inspecting the nozzles.

The most significant observation is that the inspection did not reveal indications in any of the 49 CRDM nozzles. The inspection was limited to the portion of the internal surface of the nozzle wall that is most susceptible to PWSCC. The inspection surface area extended 2 in. above the uphill end of the partial penetration weld and 2 in. below the downhill end of the weld, as shown in Figure 2. Westinghouse performed the inspection using transducers (probes) whose capability was demonstrated by inspecting the mock ups with artificial defects at the EPRI Non Destructive Evaluation (NDE) Center. The mock ups were designed to replicate all the significant variables found in previous field inspections. The remote controlled equipment used for this inspection had been successfully employed earlier for nozzle inspections at Doel 1 in Belgium and at Angra 1 in Brazil.

The absence of nozzle cracking could be explained as follows. The Point Beach 1 nozzles were fabricated from pipe material and heat treated at about 1725 °F for 1.5 h and then air cooled. In contrast, the Bugey 3 nozzle, and the nozzles at other French plants, were fabricated from forged bars and heat treated at 1508 °F if the yield strength was greater than 49.7 ksi. Thus, the Point Beach 1 nozzle material is likely to have a lower yield strength, lower residual stresses, larger grain size, and less susceptible microstructure than Bugey 3 nozzle material. It appears that these beneficial factors associated with the nozzle design and fabrication could have prevented cracking at Point Beach 1, even though this plant has been in operation for about 23 years. This time period is longer than the 10 year operation of the Bugey 3 plant when the leakage from its nozzle was detected in 1991. The setup angles for the peripheral nozzles at these two plants are the same (about 42 degrees). The estimated operating temperature for the plants are also about same; the upper head operating temperature at Point Beach is about 594 °F, whereas that for Bugey 3 is about 599 °F. These estimates take into account the core bypass of the cold leg flow into the upper head but are not validated by measurements of actual upper head temperatures. At Point Beach 1, this bypass flow is about 5 percent.

The PWSCC susceptibility of CRDM at Point Beach 1 may be compared with that of nozzles at Ringhals 2 in Sweden. Ringhals 2 is a Westinghouse 3-loop plant in operation since 1975 and has experienced nozzle cracking. Based on a microstructural study of eight samples of materials representing typical nozzle materials in Westinghouse designed plants, including Ringhals 2, it is estimated that the PWSCC initiation time for the nozzles in most of the plants is at least three times longer than that for the nozzles in Ringhals 2. Based on an analysis of yield strength, residual and operational stresses, and operating time and temperature, Westinghouse concluded that the nozzles in 45 of the 54 Westinghouse designed plants are less susceptible to PWSCC than those in Ringhals 2 where the deepest crack was 0.16 in. deep. In other words, a crack deeper than 0.16 in. would not be expected in any of the 45 plants.

We understand that the nozzles in the later designed CE reactors use forged Alloy 600 bars similar to those in the French reactors where cracking has occurred. In addition, the upper head temperatures for CE plants (594 to 617 °F) are equal to or higher than those in the French plants. In CE plants, the yield strength is slightly lower, and the attachment weld consists of a smaller amount of weld metal, which results in lower residual stresses, but this is offset by the larger setup angle (57 degrees versus 42 degrees for Bugey 3), which results in higher residual stresses. Some CE plants are in operation for longer periods than the French plants. The currently planned inspections do not include any CE plants.

Interviews were held with the licensee personnel in charge (Craig Prothero) and the engineers from Westinghouse (John Nee, inventor of the delivery tool, Greg Auld, and Dave Howell, supervisor in charge), Comex - a French company (Dehenuin Michel), AEA Technology - a British company (Gary Jeacock) and EPRI (Kim Kietzman) to discuss technical aspects of this inspection. The summaries of these discussions are presented below:

1. The layout of the CRDM nozzles is shown in Figure 3 and Table 1. Thirty-three nozzles have thermal sleeves, which hang freely inside the nozzle to guide the CRD shaft, whereas the remaining 16 nozzles do not have thermal sleeves. Of these 16 nozzles, 3 nozzles are for thermocouple columns, 4 are for part through CRDMs, and the other 9 are spares. CRDM nozzles near the center of the head have long thermal sleeves, whereas the eight peripheral nozzles, located on Ring 7 in Figure 3, have short thermal sleeves, about 0.5 in. longer than the nozzle.

2. The four outermost nozzles, which are located on Ring 8 and have no thermal sleeves, were inspected without any difficulty. These nozzles are likely to have the highest residual stresses and are most susceptible to PWSCC. Also, inspection results to date, for nozzles from European reactors, have indicated the PWSCC initiation and propagation tends to be observed on the peripheral nozzle locations with higher setup angles. Therefore, inspection results for these nozzles are likely to bound the results for other nozzles.

3. The deformation of the peripheral nozzles on Ring 7 restricted the access for the inspection tool. The deformation included ovalized cross section and bending of the nozzle. Two of the eight nozzles were inspected for 60 percent of the circumference, three for 70 percent, one for 75 percent and the remaining two for about 95 percent. In some cases, the boric acid deposits in the gap between the nozzle and the sleeve obstructed the access; however, such obstruction could be removed by rotating the thermal sleeve.

4. The inspection system consists of a delivery system, end effectors, a metal blade called a sabre, and a transducer (probe) mounted on the tip of the blade. EC transducers are used to detect the crack and ultrasonic transducers to size it. The delivery system and EC transducer are designed by Westinghouse, the ultrasonic transducers by AEA Technology of the United Kingdom, and the sabre is manufactured by Comex, a French company. The ultrasonic transducers are based on the tip diffraction principle. The current industry practice for inspecting CRDM nozzles for PWSCC on the internal surface is eddy current testing (EC) for detection and ultrasonic testing (UT) for sizing detected indications. UT is capable of detecting cracking, but is slow compared to EC. In some cases, UT is also used to locate the CRDM nozzle seal weld.

5. With this inspection system, the nozzle internal surface can be examined directly by inserting the blade (sabre) into the nozzle sleeve gap. Thus, cracks as shallow as 1 mm can be detected. In addition, information on the crack length can be obtained more accurately; and small, closely spaced cracks can be resolved. The primary physical limitation to this approach is that the gap can vary by as much as 30 percent. This is due to sleeve that may not be centered and nozzles that are deformed (bending and ovalizing) during installation. This variation in the gap can prevent direct inspection of some nozzles. Especially for the outermost nozzles which usually have greater deformation due to larger setup angles. As discussed, this physical limitation was experienced during the Point Beach 1 nozzle inspection.

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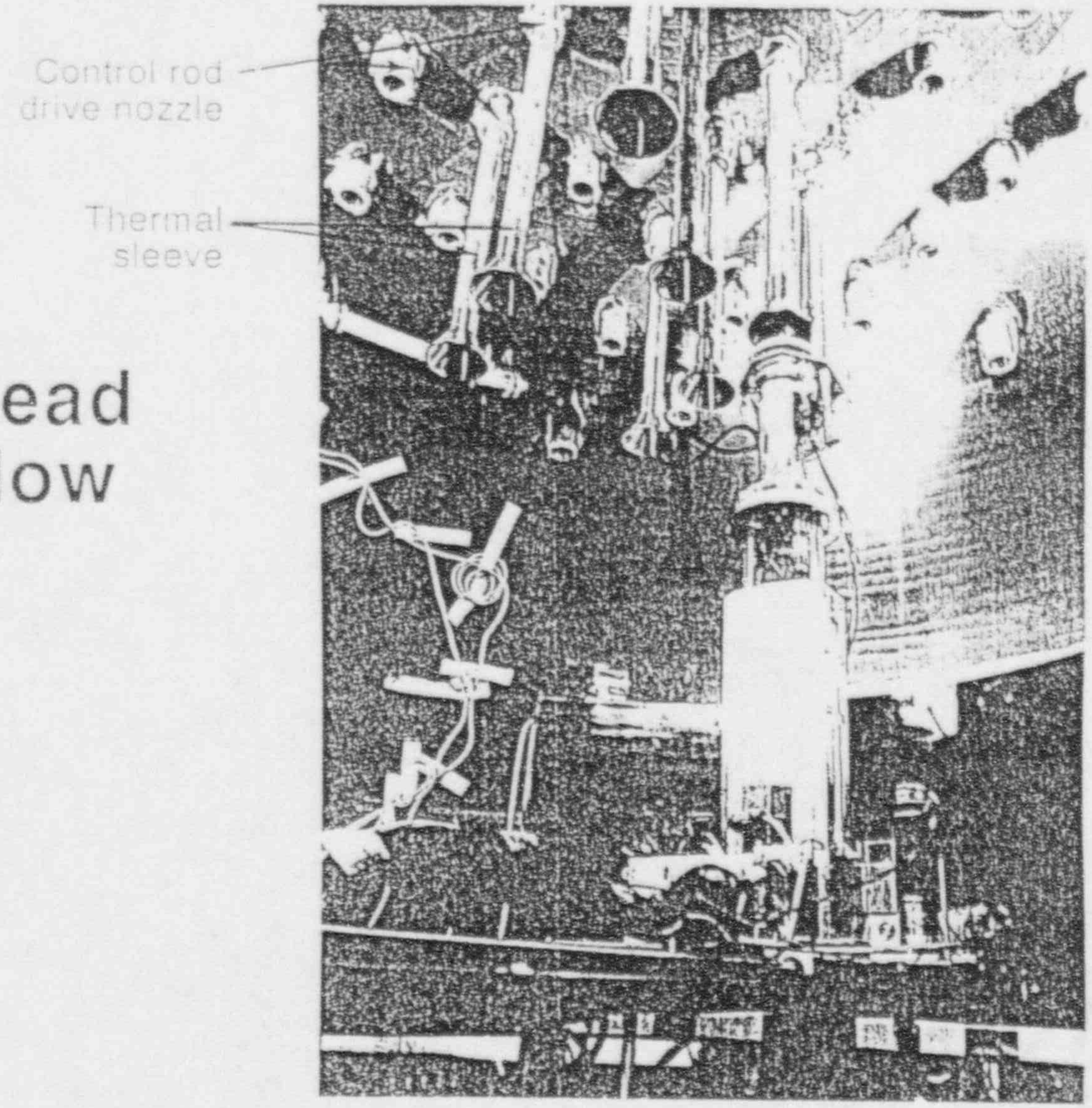
PWR Vessel Head
View from Below



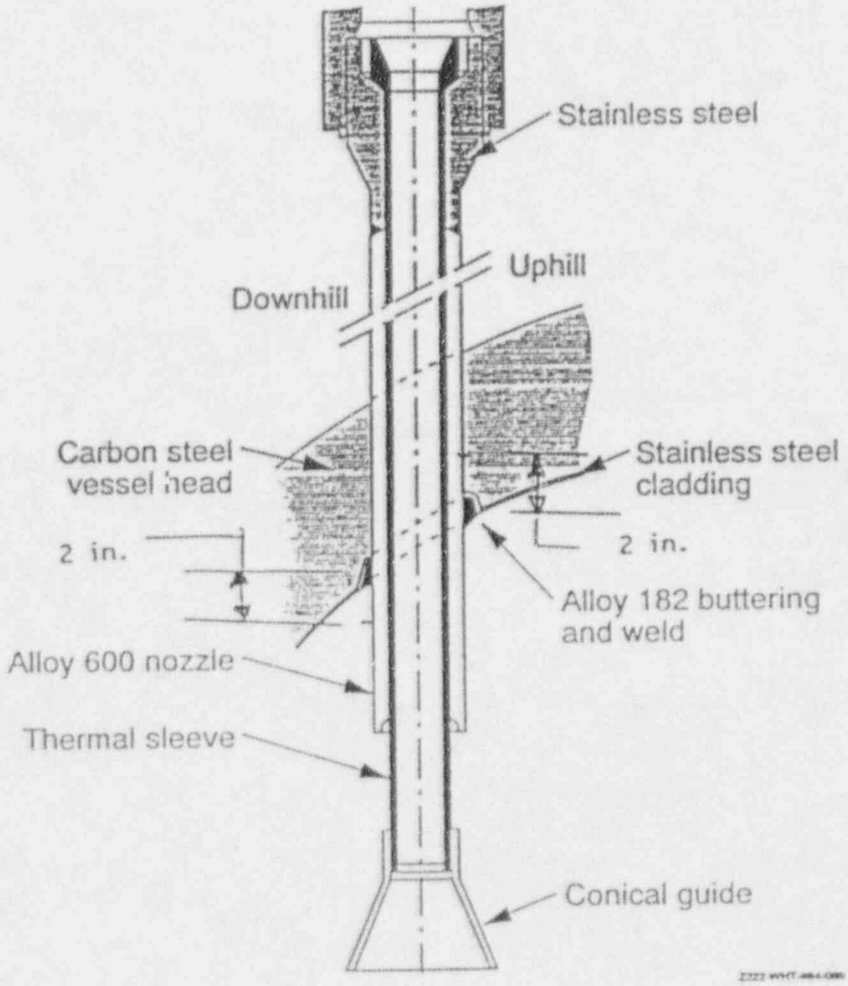
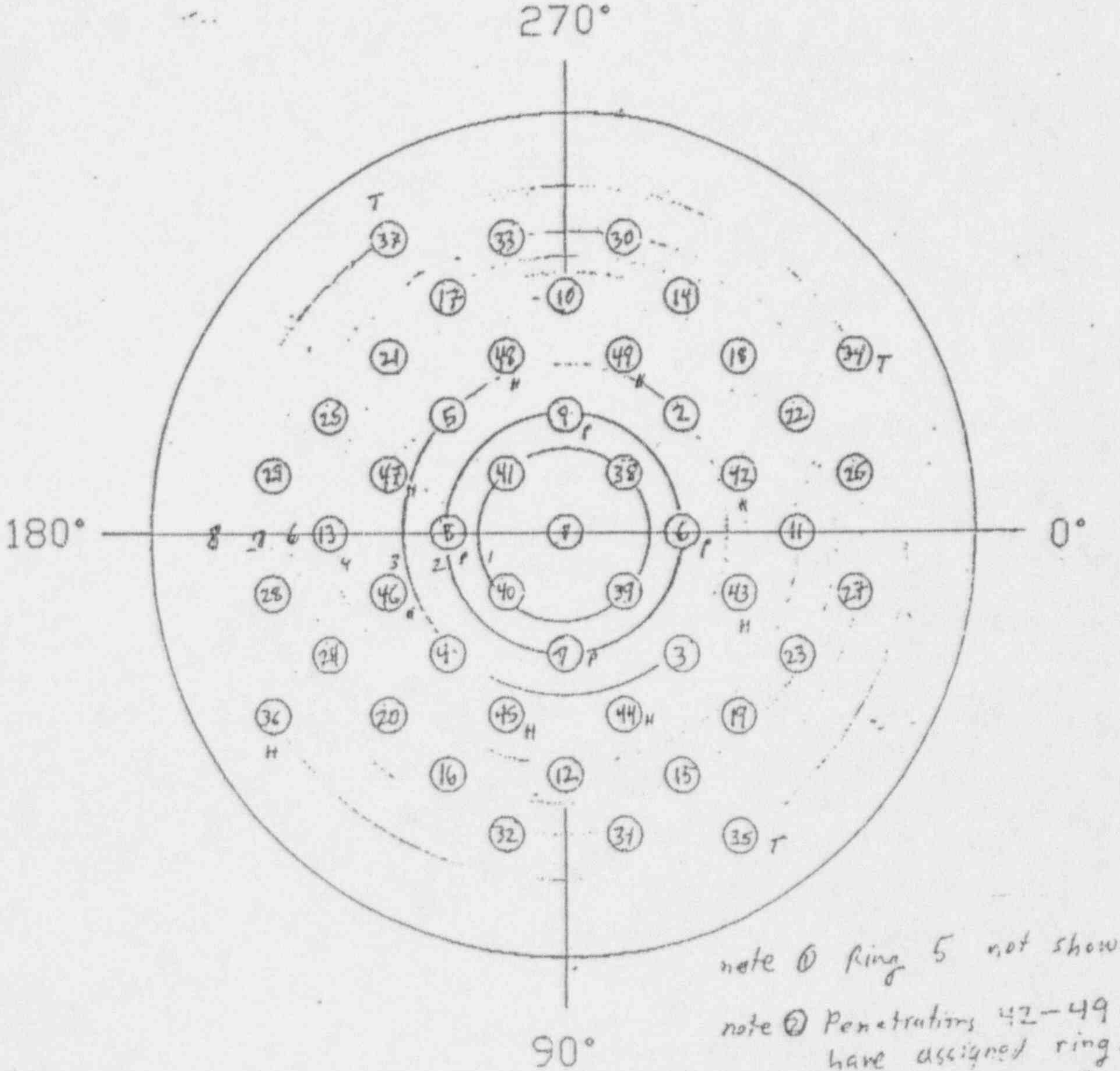


Figure 2 Typical reactor pressure vessel control rod drive nozzle.

REACTOR VESSEL ALLOY 600

POINT BEACH UNITS 1 & 2 SPECIFIC DATA



note ① Ring 5 not shown

note ② Penetrations 42-49 do not have assigned ring. Angle between 19-27°

Symbol	Component	Number	Thermal Sleeve
F	Full Length CRDM	33	Yes
P	Part Length CRDM	4	No
T	Thermocouple Column	3	No
H	Head Adapter Plug	9	No

Figure 3

Table 1

TYPICAL WELD OFFSETS

	RING NUMBER	PENETRATION NUMBER	WELD OFFSET	ANGLE
2-LOOP				
	0	1	0.00	0°
	1	38 thru 41	0.67	9.5°
	2	6 thru 9	0.96	13.5°
	3	2 thru 5	1.39	19.2°
	4	10 thru 13	2.11	27.8°
	5	18 thru 21	2.27	29.6°
	6	14 thru 17	2.44	31.4°
		22 thru 25	2.44	31.4°
	7	26 thru 33	2.95	36.4°
	8	34,35,36	3.70	42.8°