cc

Harry H. Voigt, Esquire
LeBoeuf, Lamb, Leiby and MacRae
1333 New Hampshire Avenue, N.W.
Suite 1100
Washington, D.C. 20036

Mr. Michael Slade
12 Trailwood Circle
Rochester, New York 14618

Ezra Bialik
Assistant Attorney General
Environmental Protection Bureau
New York State Department of Law
2 World Trade Center
New York, New York 10047

Resident Inspector
R.E. Ginna Plant
c/o U.S. NRC
1503 Lake Road
Ontario, New York 14519

Stanley B. Klimberg, Esquire
General Counsel
New York State Energy Office
Agency Building 2
Empire State Plaza
Albany, New York 12223

Dr. Emmeth A. Luebke
Atomic Safety and Licensing Board
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dr. Richard F. Cole
Atomic Safety and Licensing Board
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dr. Thomas E. Murley
Regional Administration
Nuclear Regulatory Commission
Region I Office
631 Park Avenue
King of Prussia, Pennsylvania 19406

U.S. Environmental Protection Agency
Region II Office
ATTN: Regional Radiation Representative
26 Federal Plaza
New York, New York 10007

Herbert Grossman, Esq., Chairman
Atomic Safety and Licensing Board
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Supervisor of the Town
of Ontario
107 Ridge Road West
Ontario, New York 14519

Jay Dunkleberger
New York State Energy Office
Agency Building 2
Empire State Plaza
Albany, New York 12223

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

EVALUATION OF RCS THERMAL SLEEVE PROBLEMS IN WESTINGHOUSE PLANTS

ROCHESTER GAS AND ELECTRIC CORPORATION

R. E. GINNA NUCLEAR POWER PLANT

DOCKET NO.50-244

I. INTRODUCTION

For Westinghouse PWR plants, thermal sleeves have been used in the past at those reactor coolant system branch line nozzles where a rapid thermal fluctuation exists due to mixing of flows with different temperatures. The intent was to reduce or eliminate thermal stress of the nozzle wall, since the temperature fluctuations produce rapid varying high stresses in addition to the normal stresses present in the component.

Thermal sleeves have been traditionally installed at the following locations:

For a 3 loop plant, a total of 8 sleeves were installed: (1) one at the nozzle of 14" pressurizer surge line, (2) three at the nozzles of 5" cold leg safety injection lines, (3) three at the nozzles of 12" accumulator lines, and (4) one at the nozzle of 3" charging line.

For a 4 loop plant, a total of 7 sleeves were installed: (1) one at the nozzle of 14" pressurizer surge line (2) four at the nozzles of 10" accumulator lines with safety injections, and (3) two at the nozzles of 3" charging lines.

Design evolution of the thermal sleeves has resulted in a total of five generations, which were designated by Westinghouse as generation 0, 1, 2, 3 and 4 (Figures 1, 2, 3, 4, and 5). Sleeves of different generations were used in different Westinghouse plants built at different times. The evolution in sleeve design from generation to generation followed the general state-of-art capability of more sophisticated analysis.

II. THERMAL SLEEVE PROBLEMS

Since mid-1982, loose thermal sleeves or sleeves with cracked attachment welds were found successively in several operating Westinghouse plants, namely Trojan, McGuire, North Anna 1 and 2. The following provides a brief description of such events:

A. Trojan Plant: (Ref. 1 to 3)

During the June 1982 refueling outage, an underwater TV inspection of reactor vessel internals revealed several loose metal objects beneath the lower core plate. Subsequent investigation by Westinghouse and the Utility concluded that the loose parts were four thermal sleeves from the nozzles of 10" accumulator lines in all four loops. All loose sleeves had migrated through the cold leg into the reactor vessel. One of the loose sleeves was broken into several pieces but all four sleeves were recovered. Radiographic examinations of other similarly designed sleeves on the unit revealed one broken weld and a slight movement of the 14" pressurizer surge line nozzle sleeve as well as a cracked weld in one of the two 3" charging lines. Failed sleeves were all removed. Justification for sleeve removal was reviewed by the staff. The plant was permitted to continue operations until next extended outage pending generic resolution of the sleeve problems.

B. McGuire Plant: (Ref. 4 to 7)

At nearly the same time as in the Trojan plant, a similar 10" accumulator nozzle thermal sleeve was found missing during the June 1982 outage for steam generator maintenance. Based on signals from loose part monitoring, the licensee concluded that the missing sleeve was located in the lower reactor internals. The welds of the remaining sleeves were shown to be intact by radiographic inspections. All sleeves remaining in place were removed and the missing sleeve is expected to be recovered at first refueling outage or the first extended outage period. Justification for operation until next extended outage with the unrecovered sleeve was accepted by the staff. Operation beyond that point requires the generic resolution of the sleeve problems.

In light of the occurrences in Trojan and McGuire Unit 1, McGuire Unit 2 started operations without any thermal sleeves installed in the reactor coolant system nozzles.

C. North Anna Plant: (Ref. 8 to 11)

In the summer of 1982, radiographic examination was conducted of RCS pipe welds during the plant outage. On Unit 1, one sleeve at the 6" safety injection nozzle was found missing and was later recovered from the bottom of reactor vessel. In addition, the sleeve at 3" charging line nozzle was found to have cracked attachment welds and was subsequently removed. Examination in Unit 2 also revealed that four thermal sleeves had cracked welds and were removed. The plant resumed operation with six intact sleeves in-place in Unit 1 and with four intact sleeves in-place in Unit 2. Justification to continue operations until the next outage was reviewed and accepted by the staff. Operations beyond that point will requires generic resolution of the sleeve problems.

D. V.C. Summer Plant: (Ref. 12 & 13)

Because of the foregoing occurrences in other Westinghouse plants, NRC was informed in July 1982 that all eight thermal sleeves in the reactor coolant system were to be removed prior to plant startup. Justification for operation until the next extended outage was provided and was reviewed and accepted by the staff. Similarly, Summer will implement the generic resolution when it becomes available.

III. PROBLEM CAUSES

Westinghouse investigation concluded that these occurrences have been confined to those thermal sleeves of "Generation 3" design (Figure 4), which utilize

2 fillet welds 180° apart at the upsteam attachment, instead of a continuous 360° weld used in other design. The failures were attributed to attachment weld cracking, which was caused by high cycle fatigue due to flow induced vibrations. The failure mechanism was substantiated by metallurgical evidence found at the failed welds. Initiation of cracks occurred on the ID and failure occurred through transgranular cracks propagated by the failure mechanism. Westinghouse has also indicated that sleeves of earlier design (i.e. Generation 0, 1, 2) remain intact due to the fact that earlier design codes required the use of larger design margins.

IV. SUMMARY OF CORRECTIVE MEASURES

Further investigation conducted by Westinghouse using the latest analytical capability has concluded that thermal sleeves are not really needed to maintain the structural integrity of nozzles under thermal transients induced by injection flows. Thus the corrective measures investigated by Westinghouse and implemented by the utilities consist of the following actions:

A. For operating plants experiencing failed sleeves;

1. Generation 3 Sleeves with cracked welds found were removed in all cases, (i.e. Trojan, McGuire 1 and North Anna 1 & 2).

2. Remaining Generation 3 sleeves with intact welds were either removed (i.e. McGuire 1) or retained (i.e. Trojan and North Anna 1 & 2).

3. Detached sleeves were either recovered and removed (i.e. Trojan and North Anna 1) or remain inside the reactor vessel until the next refueling outage, or next outage of extended period (McGuire 1) at which time they are planned to be removed. The above measures were justified on the basis that (1) nozzle integrity will be maintained without sleeves, (2) intact sleeves are unlikely to have rapid degradation by judging the pace of events, and (3) the loose parts

of detached sleeves inside the reactor vessel will not cause safety concerns.

B. Four plants ready to start initial operation with "Generation 3" sleeves have had them completely removed (i.e. V. C. Summer, McGuire 2).

C. For plants still under OL review, decisions have been made either not to install thermal sleeves in the reactor coolant system (i.e. Catawba, South Texas, etc.) or to use sleeves of improved design, the "Generation 4" sleeves (i.e. Vogtle and Seabrook).

V. STAFF EVALUATION

Staff review of the thermal sleeve problems which occurred in Trojan, McGuire and North Anna plants were conducted in two phases. The initial phase was to perform a plant specific review to justify continued operation for a specified period. (Ref. 3, 7, 8, 11; 13). The final phase was to obtain generic resolution of all Westinghouse plants (Ref. 14 to 17). The following is a summary of staff findings and conclusions of the final phase:

1. By comparing the configuration of the various generations thermal sleeves (Figure 1 to 4), the "Generation 3" sleeve is the only design utilizing two brief welds 180° apart at the upstream attachment, instead of a continuous 360° weld as used in other designs. Consequently Generation 3 design sleeves are (a) subjected to more severe excitation due to bypass flow through the unwelded gap, and (b) the sleeves are more flexible and responsive to flow excitation due to less rigid constraint at the weld attachment. Thus high cycle stresses due to flow-induced vibration cause fatigue failure at the attachment welds. We concur with the Westinghouse finding on failure mechanism as described in Paragraph III above, and our evaluation also conclude that the 360° weld for "Generation 4" sleeves is justifiable and acceptable.

2. Based on the effects of the unique design of "Generation 3" sleeves as stated in Item 1 above and the fact that sleeves of former design (i.e. Generation 0, 1, 2) had reported no failure after much longer periods of in-plant service (Table 1), we concur that the thermal sleeve problems are confined to the "Generation 3" sleeves only. Thus the sleeve problem is a generic issue only to those plants using "Generation 3" sleeves.

3. We have evaluated the methods, procedures, results and acceptance criteria of detailed stress analyses performed by Westinghouse to ensure structure integrity of various size nozzles without thermal sleeves. Finite element techniques were used to calculate thermal stress effects under the most adverse operating transients, including their contributions to cumulative fatigue damage. In each analysis, the whole nozzle structure and welds to the connecting pipe were included. In addition to the operating transients, all other mechanical loads were included. The analytical results indicated that the stress and fatigue damage are within the allowable limits set by Subsection NB of Section III of the ASME Code. We conclude that such analyses and results are acceptable to verify nozzle integrity without thermal sleeves.

4. The impact and wedging effects of a loose thermal sleeve on reactor internals, steam generators, and primary systems piping have been evaluated by Westinghouse. We agree with the results of the evaluation that such effects are unlikely either to impair the reactor coolant pressure boundary or to cause unacceptable safety concerns due to the limited available impact energy which can be imparted on randomly targeted mechanical components.

5. Our justification to permit operation of Trojan, McGuire, and North Anna to continue for the period previously described is based on our evaluation as stated in Item 3 and 4 above.

6. Westinghouse has presented the historical background in the design and analyses evaluation of connecting nozzles. Currently, due to the advancement of analytical technology, two-D and three-D finite element modeling permits more confidence in analytical results. Heat transfer, stress and fatigue effects were evaluated under severely defined transients to check whether the requirements of the ASME Code were met. We conclude that the analytical approach and results presented in both case specific evaluations stated in Item 3 above and the generic evaluation are acceptable.

7. At our request, Westinghouse has provided a detailed list of flow transients with specified thermal variations and anticipated number of occurrences in the nozzle areas (Ref. 16). We have reviewed the Westinghouse information (Ref. 17) and conclude that these temperature variations and number of cycles assumed in their stress analyses are reasonably conservative and are acceptable for their use in the evaluation of nozzle integrity.

8. In our generic review concerning the effect of thermal cycling due to flow mixing from branch lines to the main coolant loop at the nozzle locations, we find that Westinghouse analyses are adequate for handling high cycle and low temperature difference transients. A step function of maximum temperature variation was assumed for the stress calculation and fatigue evaluation. It was found that the maximum stress so induced was below the endurance limit with adequate margins. Thus fatigue failure at a nozzle location is unlikely to occur due to this type of transients.

9. We also evaluated the effect of other type transients which have low cycle and high temperature differences. The cumulative fatigue usage factor at each nozzle location was reviewed and was within acceptable code limits. However in some locations, there is less margin available to the allowable limits. Westinghouse also indicated that detailed flow mixing information is not available. Since flow stratification during mixing is a potential mechanism to initiate

micro crack at the surface of inner pipe wall, we believe that nozzle locations with high fatigue factors may need special attention.

VI. REGULATORY POSITION

A. The following Westinghouse plants have installed thermal sleeves using design details different from the Generation 3 series. Such sleeves may remain in place.

Generation 0

R. E. Ginna
Point Beach 1
Indian Point 2
H. B. Robinson 2
Turkey Point 3
San Onofre 1
Haddam Neck
Point Beach 2

Generation 1

Salem 1
Indian Point 3
Turkey Point 4
Surry 1
Surry 2
Prairie Island 1
Diablo Canyon 1

Generation 2

Kewaunee
Zion 1
Zion 2
Salem 2
Diablo Canyon 2
Beaver Valley 1
Prairie Island 2
D. C. Cook 1
D. C. Cook 2
Sequoyah 1
Sequoyah 2

Generation 4

Vogtle 1
Vogtle 2
Seabrook 1
Seabrook 2

B. For the Westinghouse 3-loop and 4-loop plants choosing not to install thermal sleeves at the reactor coolant loop branch line nozzles, the Licensee should revise the Technical Specifications to monitor the injection flow transients which occur at the following nozzles and to evaluate their cumulative fatigue usage factors:

For 3-Loop Plants	For 4-Loop Plants
6" Cold leg safety injection	10" Accumulator with Safety injection
3" Charging	3" Charging

As long as the cumulative fatigue usage factor (CUF) at any nozzle location listed avove remains below 0.8, no action is required. When the CUF exceeds 0.8, the Licensee should prepare and submit a specific plan (i.e. more frequent inservice inspection at such nozzle locations) to ensure early detection of possible nozzle degradation for NRC approval.

The following plants are in this category:

Byron 1	Catawba 1
Byron 2	Catawba 2
Braidwood 1	Callaway 1
Braidwood 2	Wolf Creek 1
Marble Hill 1	Shearon Harris 3
Marble Hill 2	Shearon Harris 4
Comanche Peak 1	South Texas 1
Comanche Peak 2	South Texas 2

C. For operating plants using thermal sleeves of "Generation 3" design:

1. Removal of thermal sleeves at reactor coolant loop branch line nozzles is acceptable provided a program is implemented per revision of the Technical Specifications to monitor the occurrence of injection flow transients and evaluate their fatigue usage factors for nozzles specified in item B above. Action is not required until the

cumulative fatigue usage factor in a non-sleeved nozzle exceeds 0.8. When that occurs, the Licensee should propose a plan for NRC approval to ensure early detection of possible nozzle degradation.

2. For those nozzles having intact thermal sleeves, in lieu of sleeve removal the option to retain sleeves in place during continued plant operation is acceptable, provided a program to inspect attachment welds of these sleeves at each refueling outage is initiated. The program should be submitted for NRC approval.

   Sleeves should be removed or replaced should any degradation of the attachment welds be found. Action requirements after removal of sleeves are as specified in items C.1 above.

The following plants are in this category:

Trojan	V. C. Summer
North Anna 1 & 2	Watts Bar 1 & 2
Farley 1 & 2	McGuire 1 & 2

D. For plants that have not received an operating license and that originally planned to use "Generation 3" thermal sleeves, the following options are acceptable:

1. Remove thermal sleeves and implement requirements specified in Item B above.

2. Replace sleeves by those other than the "Generation 3" design and implement requirements specified in Item A above.

3. Retain sleeves of "Generation 3" design in place and implement requirements specified in Item C.2 above.

The following plants are in this category:

Shearon Harris 1 & 2
Millstone 3
Beaver Valley 2

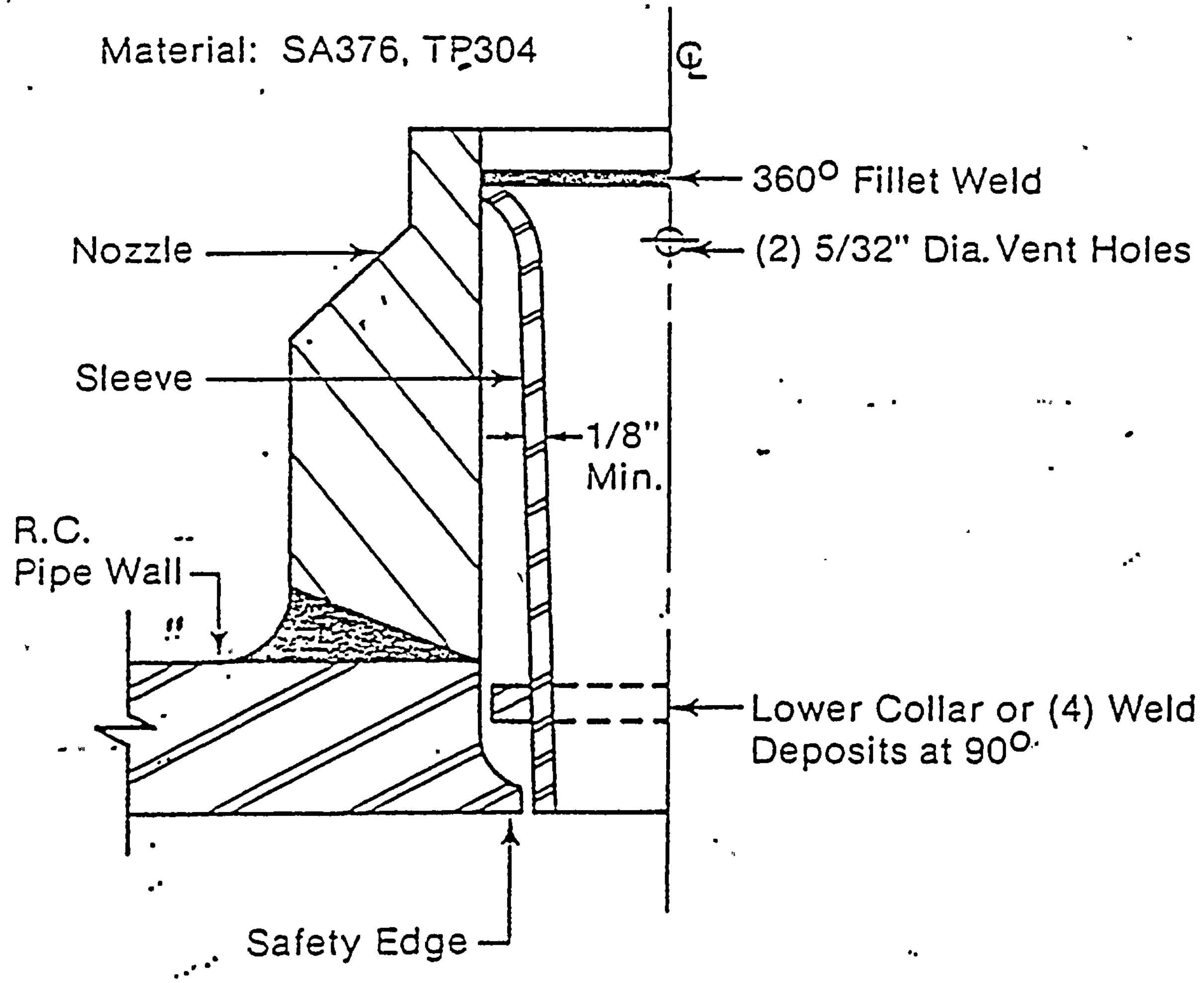
Table 1

OPERATING HISTORY

THERMAL SLEEVE GENERATION	NUMBER OF OPERATING PLANTS/TOTAL	APPROX YEARS ON LINE
0	8	93 (9-12)
1	6/7	50 (6-10)
2	9/11	55 (1-9)
3	6/14	19 (1-7)
4	0/4	0

Figure 1

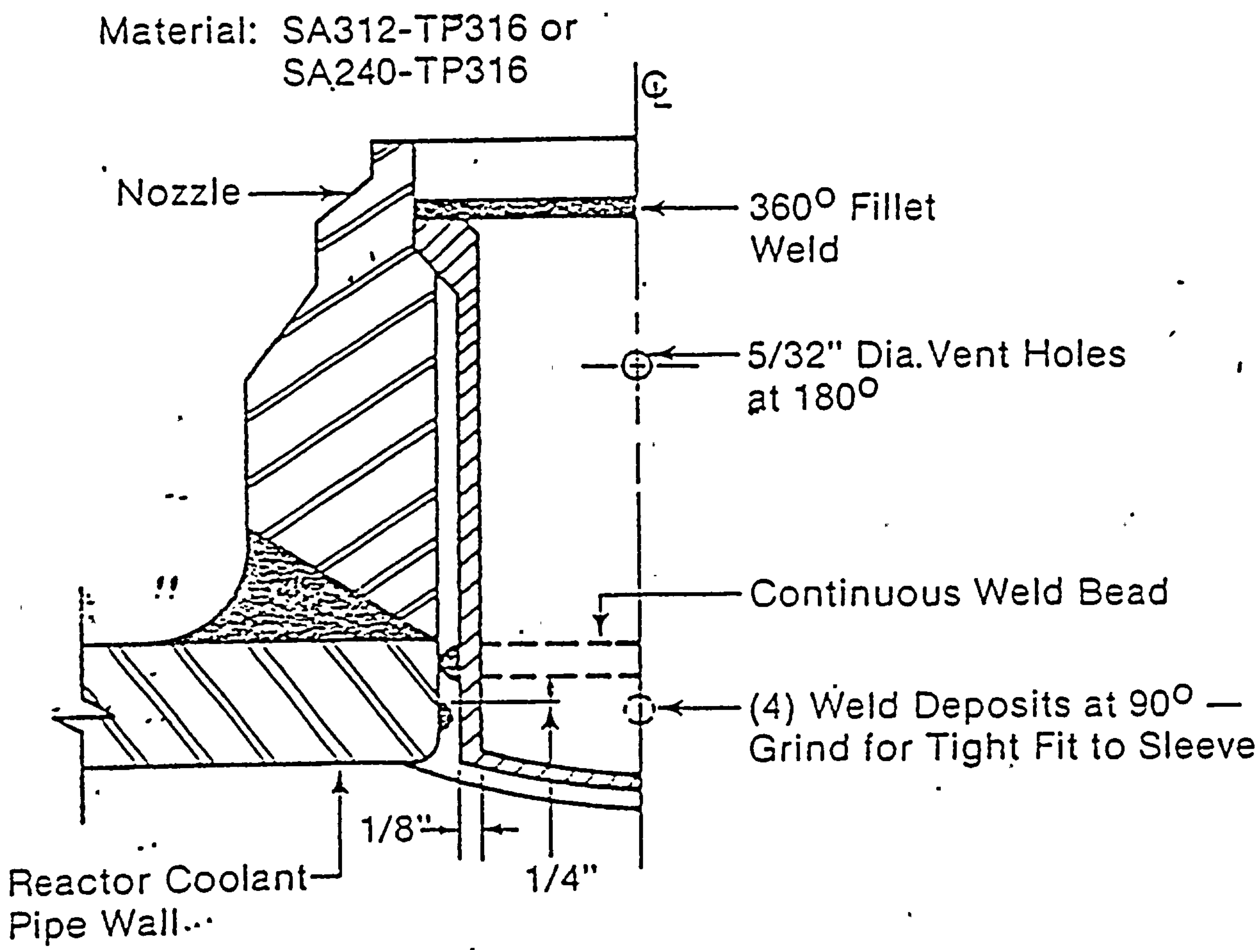
ORIGINAL DESIGN THERMAL SLEEVE BUTT WELD NOZZLE



Note: Typical for 3" and larger nozzles

Figure 2

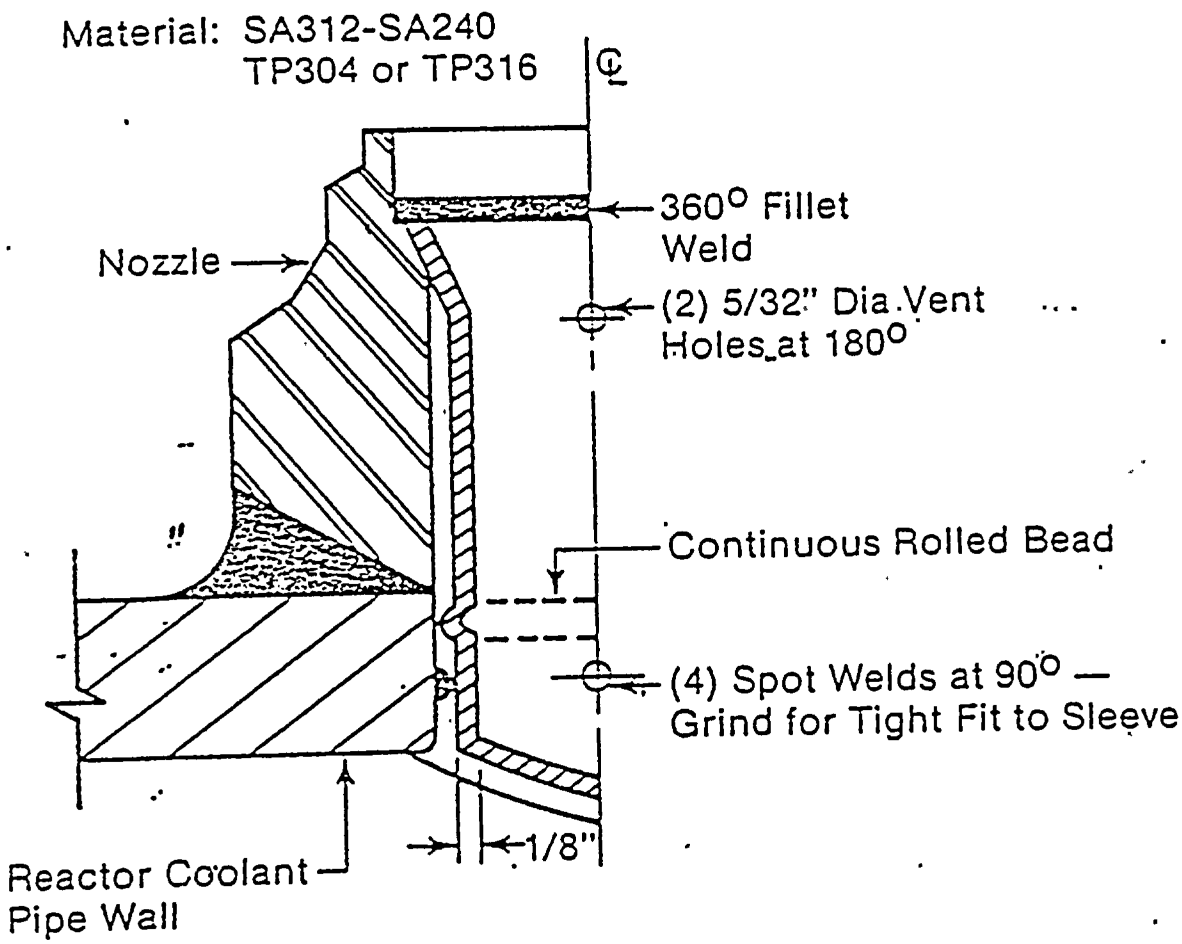
FIRST GENERATION THERMAL SLEEVE BUTT WELD NOZZLE



Note: Typical for all 3" and larger nozzles

FIGURE 3

SECOND GENERATION THERMAL SLEEVE BUTT WELD NOZZLE



Note: Typical for all 3" and larger nozzles

FIGURE 4

THIRD GENERATION THERMAL SLEEVE BUTT WELD NOZZLE

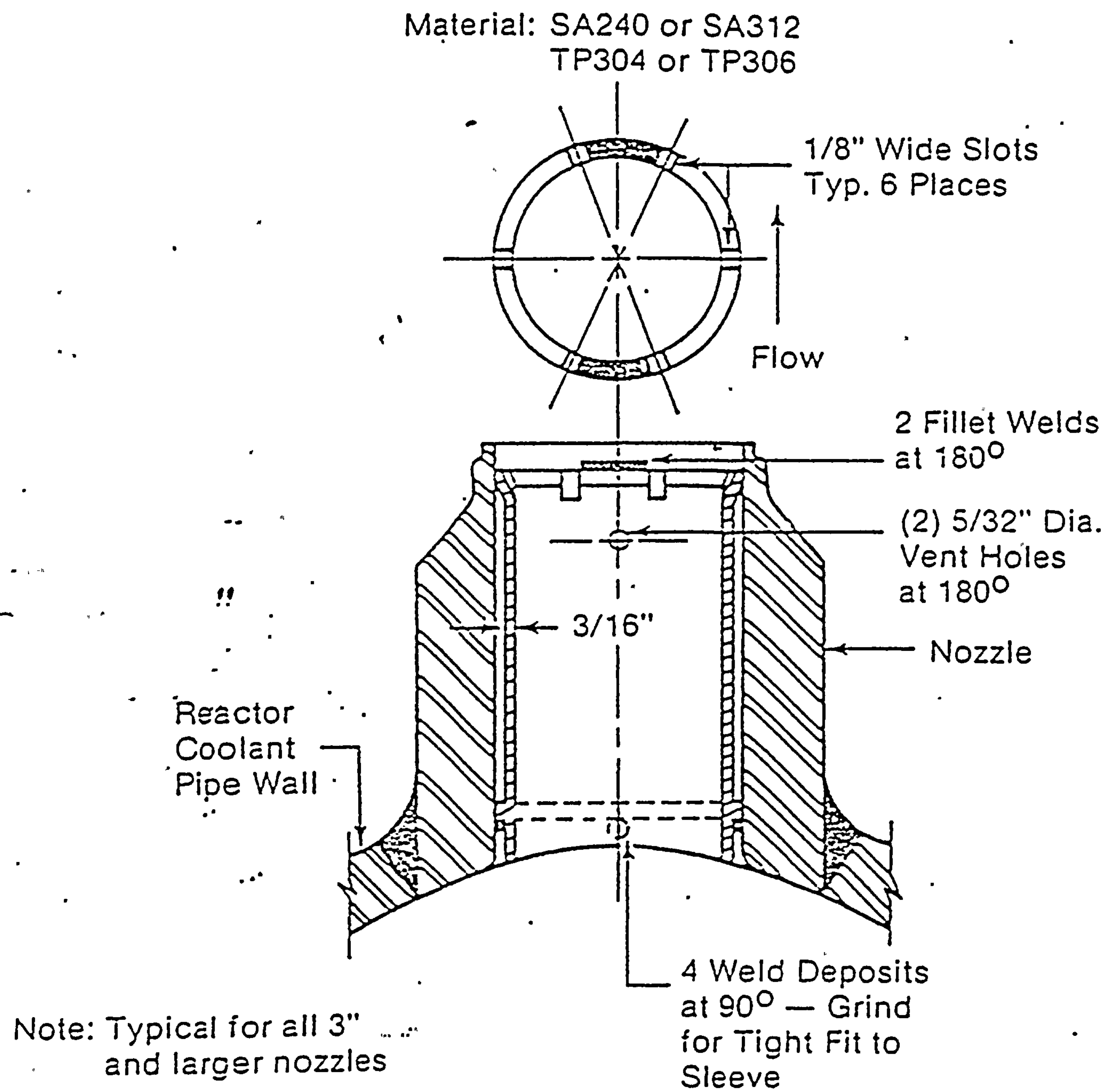
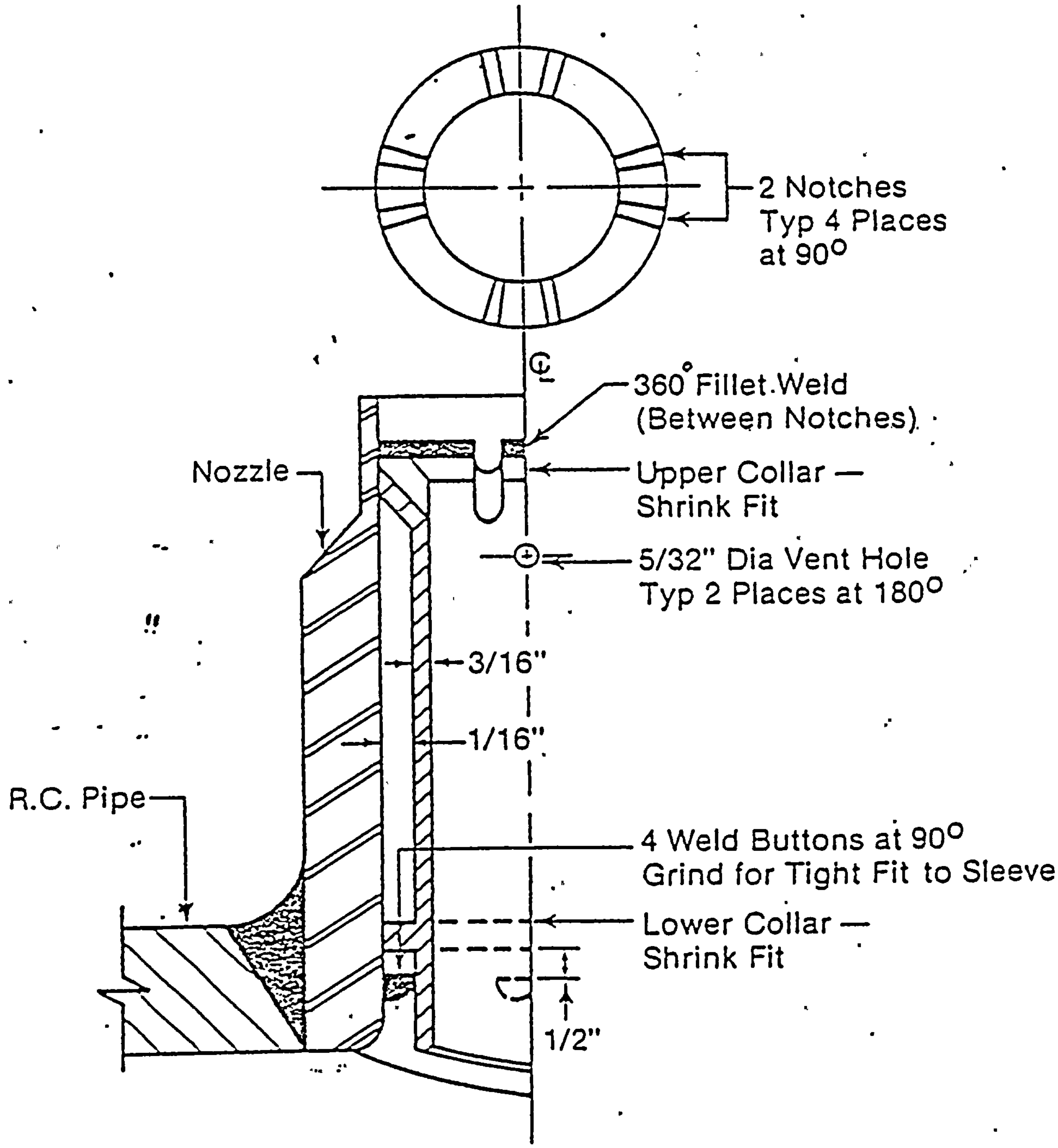


FIGURE 5

FOURTH GENERATION THERMAL SLEEVE BUTT WELD NOZZLE



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