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REACTOR COOLANT SYSTEM

ASYMMETRIC LOADS

FINAL REPORT

PIPE WHIP RESTRAINTS (APPENDIX C)

A PLAN FOR THE FRACTURE ANALYSIS OF FORT CALHOUN COLD LEG PIPING (APPENDIX D)

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for

FORT CALHOUN

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PIPE WHIP RESTRAINTS

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Pipe Whip Restraint System

C.1. Pipe Restraint Lugs

Feasibility studies were performed for the addition of pipe restraint systems which would limit the blowdown area of the postulated guillotine pipe break at the reactor vessel terminal end of the pump discharge leg. In order to effect a sufficient reduction in the primary shield wall load, it was determined that the break size would have to be limited to 100-150 square inches (versus about 900 sq. in. total for a double ended guillotine). Such a small partial area break size would require a close fitting pipe restraint to limit pipe motion.

The pipe restraint concept selected for detailed study consists of a set of three lugs integrally welded to the outer surface of each of the 4 pump discharge legs, which mate with restraint structures fastened to the building structure. (See Figure C-1). The lugs are separated from the restraint structures by a gap during normal operation. In the event of a guillotine pipe break at the reactor vessel terminal end, the lugs would come into contact with the restraint structure and limit the axial displacement of the pipe, thereby limiting the resultant break flow area. The radial displacement of the end of the broken pipe would not exceed the pipe wall thickness, therefore the break flow area would be totally due to the axial displacement only.

Each pipe lug would be about 11 1/2 inches long (axially) by about 9 inches wide (circumferentially) and about 6 inches high in the radial direction. Contact with the mating restraint sturcture would be on the face of the lug perpendicular to the pipe centerline on the side away from the reactor. The lugs would be oriented $\pm$ 45 degrees above and below the horizontal centerline of the pipe on the side of the discharge leg away from the steam generator, and on the horizontal centerline of the discharge leg on the side toward the steam generator. The lugs would be located near the elbow end of the straight section of pipe between the reactor vessel inlet nozzle and the pump discharge leg elbow, inside the primary shield wall penetration. Each lug is sized to accommodate a 700 kip load, or 2100 kips total for all 3 lugs on each pipe.

C.2. Pipe Restraint Analysis

A non-linear time history dynamic analysis of the RCS was performed for a postulated RV inlet guillotine break. This was done to verify that the proposed pipe restraint system would limit the break opening area to less than 100 in.^{2} and to insure that the 700^k design load on each lug would not be exceeded.

Lumped parameter models were used which include structural details of the steam generator (SG), reactor coolant pump (RCP), reactor coolant system (RCS) piping, and discharge leg restraint system. Mass detail was emphasized at the SG, RCP, and the discharge leg pipe of the RCS broken loop. Non-linear characteristics were included for the SG vertical supports and LOCA ring (modeling of the LOCA ring reflects the modifications which were made to the supporting rods, RCP vertical and horizontal supports, and the discharge leg restraint system. To insure conservative determination of break opening size, credit was taken only for those RCP supports for which it could be demonstrated that design loads were not exceeded.

The flexibility effects of the restraint lug, energy absorbing material, and supporting structure were incorporated into the load deflection characteristics of the restraint system.

The forcing function consisted of a suddenly applied pipe tension release force at the broken pipe end.

The results of the analysis described above consist of the time history motion of the broken end of the RCP discharge pipe. These motions, together with motions on the RV nozzle in the broken loop, determine the maximum opening size for a break at the RV inlet nozzle. Maximum displacements and break opening area are presented in Table C-1. Loads on each lug are limited to a value less than the 700^k design load by inclusion of the energy absorbing material between the lug and supporting structure.

C.3. Conceptual Design of Structural Restraining System

Several alternative conceptual designs of structural restraining systems that would interface with the pipe lugs described in Section C.1 have been investigated. All such designs act to restrain the motion of the broken pump discharge piping along its axis. Analyses performed have indicated that the motion in the direction normal to the axis of the pipe would be limited so that separation of the pipe edges would be significantly less than the pipe wall thickness, so long as the axial separation is limited to a small value, nominally equal to 0.6 inches. Restraining of the pipe motion in a direction normal to its axis would, therefore, be unnecessary.

Of the schemes studied, the one described herein is the most readily accomplishable, the one resulting in the least quantity of concrete removed, and requiring the least predicted personnel exposure.

The restraining system, is conceptually designed to have a stiffness of at least 10×10^6 lb/in., and utilizes a crushable material in the vicinity of the interface with each pipe lug, designed to limit the maximum reaction load on the lug to approximately 600 kips. The axial deflection of the lug, including the closure of the 1/8 inch gap between the lug and the transition piece to the crushable material, the displacement of the crushable material and the displacement of the restraining structure proper (the latter being negligible) is limited to 0.6 inches.

A solid transition piece of metal is used to distribute the load imparted by the lug bearing area of approximately 20 square inches over the surface of the crushable material. That area is required to guarantee crushing of the material at approximately 600 kips, and sufficient bearing area when crushed.

Different energy absorbing materials could have been used. For the conceptual design, the choice of Hexcel material was made. The Hexcel crushable thickness required is approximately 5/8 inches.

The restraining system that can be conceptually employed at each of the four cold leg penetrations, varies with the penetration because of differences in geometrical arrangement of walls in the vicinity of the penetration and of interferences from ducts, cable trays, equipment and piping.

C.4. Restraint System Conceptual Design Details

The conceptual design details of the restraining system consists of the following:

a) At three of the four penetrations the structure which interfaces with the horizontal lug is independent from the structure interfacing with the lugs located 45^0 above and below the pipe horizontal centerline on the opposite side. This structure is a fully welded built-up plate structure, with steel plates approximately 2 inches thick which are attached to the concrete wall at the penetration periphery by means of four (4) 2 1/2 inch diameter, 42 inch long, rock anchor bolts, which must be fanned out to permit drilling into the concrete without interference from the pipe itself.

   Drilling of the concrete may result in interferences with wall reinforcement necessitating redrilling as the rebar emplacement cannot be known with exactness.

   At the fourth penetration this restraining scheme cannot be utilized, because of interference from the roof and floor of a 4 foot high ledge which separates the exit of the penetration from the pump room proper.

b) Two of the penetrations (northeast and southeast) terminate near the shield walls which surround the pump and steam generator compartments. The limited space between the penetration and those walls, as well as the angle between the penetration and the wall make it impossible to use a restraining scheme similar to that described in (a) above to interface with the two lugs at 45^0 from the horizontal.

   In this instance the load from both lugs is transmitted back through the transition piece and the crushable material to two built-up plate structures in the shape of pyramids which are in turn welded to a 2 inch thick plate, approximately seven feet by five feet in dimension, which is contoured to avoid interference with cable trays and ducts passing through the pump room wall. This plate is connected to a matching plate on the far side of the wall by eight (8) 2 1/2 inch through bolts. The weight and the interferences with the plate would make it impractical to build it outside and move into position in one piece. Hence, a considerable amount of assembling and welding would have to be done in place.

Drilling of the concrete could again present the problem with interference with rebar.

c) The type of restraint described above, is not feasible for two western penetrations because of interference from the ledge described in (a) above in one instance and of a re-entrant space in another. In the latter case (northwest penetration) a built-up column which has the crushable material and transition piece at the lug end, carry the load to the wall opposite the penetration exit. There the built-up columns are welded to 3/4 inch plates which are attached to the concrete wall by 30 7/8 inch anchors.

Cinch anchors have to be used because of the very restricted space in which work would have to be performed, which restricts the length of the drill which can be used.

d) The southwest penetration exits onto a ledge approximately four feet high by four feet wide. This severely limits the work that can be done in the immediate vicinity of the penetration exit. The conceptual scheme for the restraining system at this penetration therefore calls for three (3) vertical columns, welded above and below the outside edges of the ledge to a built-up plate structure.

Each of the upper and lower built-up plate structures is anchored to the concrete by means of six (6) 2 1/2 inch high strength rock anchors. The load is transmitted from the 45^{o} lugs to one of the vertical columns and the side of the ledge by two horizontal beams tied together by a vertical strut which also acts to support their weight by transferring it to the floor of the ledge.

Because of the angle made by the ledge with the penetration, the load from the horizontal lug must be transmitted to two vertical columns, again through horizontal beams tied together to a vertical strut resting on the ledge floor. The vertical struts carry the crushable material and transition pieces.

All construction utilizes 2 inch thick plates with full penetration welds.

C.5. Modification Uncertainties

An optimistic estimate of the time of fabrication, drilling, installation, and cleaning up for an eventual implementation of such a scheme for restraining pipe motion following rupture, is in the neighborhood of 54,000 manhours excluding the time required for the installation of the lugs. Approximately one-half of this time would be spent in radiation areas of 200 mrem/hr or more. Hence, the man rem exposure from such a modification would be in excess of 5,400 man rem. In actuality, the time is likely to be even longer and the exposures higher.

It must be emphasized that the preceding is a conceptual design, and that even though this conceptual design of the restraint system appears possible on paper, there are many considerations that might render it impractical in reality. Items which may cause the concept to be impractical, but are not amenable to precise evaluation are:

a) Radiation levels in the area may be locally higher than planned for, thus limiting the time that can be spent by individuals in the area to an impractical level; i.e., virtually no real work can be performed since individuals would have little time left other than that spent in entering and leaving the area.

b) Airborne particulate contamination generated during drilling may require respirator usage on a continuous basis, rendering work extremely inefficient, if not impractical.

c) Drilling of concrete will likely hit rebar, necessitating repair of concrete rebar and redrilling.

d) Equipment for drilling may in practice not fit in the space available together with the personnel handling it. Likewise for lifting equipment, etc. Hence, new equipment may have to be designed or a new scheme developed. Although mock-ups would prevent this from occurring during the actual implementation, it cannot be said for certain whether the conceptual design can be implemented until the mock-up has been built and used.

e) There may not be a sufficient number of qualified welders in the Omaha area to permit all welding necessary in the radiation area to be accomplished in the estimated time.

f) There may be interferences from cable trays, piping, ducts, etc., which do not show in the drawings utilized for the feasibility study of the conceptual schemes.

C.6. Estimated Costs

To assist in selecting a solution to the existing analytical uncertainty of the shield wall the dollar and man rem costs associated with the potential modifications were estimated. The estimates were based on the following major assumptions:

a) The radiation field, in the work area, averages 200 mrem per hour.

b) Each worker will require two days of health physics and site security training.

c) Welder qualification and mockup training will be conducted as necessary.

d) Sufficient Construction Management personnel will be assigned to assure effective coordination of the work.

e) Work Schedule

1. Lug Installation

   Two (2) ten hour shifts, six days per week.

2. Restraint Installation

Three (3) eight hour shifts, seven days per week.

C.6.1. Lug Installation

Costs of the lug installation, including final design, material, craft labor, supervision, technical assistance and quality control is $1,122,400.00. It is estimated that 830 manhours will be required for each lug for a total of 9,960 manhours. Due to the 200 mrem per hour radiation field, the task is expected to require 156 qualified welders. Virtually all of the installation time for the lugs will be spent in the 200 mrem per hour radiation field resulting in an exposure of 1,800 man-rem.

C.6.2. Restraint Installation

Costs of the restraint installation, including final design, material, craft labor, supervision, quality control and contingencies is $10,433,000.00.

C.6.3. Replacement Power

The controlling path of the outage will be restraint installation. It is estimated that this effort will require 150 days. Prior to starting the work, however, the plant must be brought to a cold shutdown condition and sufficient lug work must be done to enable the restraint crews to begin their work. Thus, it is estimated that the total length of the required outage will be 165 days. Based on Cycle-6 nuclear fuel costs and current coal prices, the differential between nuclear and coal generation at OPPD is currently $7.70 per megawatt hour. Assuming that the outage will be taken after the stretch rating at Fort Calhoun is achieved, that electrical rating will be 487.5 megawatts. The daily differential cost between nuclear and coal is more than $90,000.00. The cost for the entire outage would be $14,864,850.00.

C.6.4. Cost and Man Rem Summary

The total known costs for these modifications is $26,420,250.00. It must be emphasized that there are many unknown contingencies which cannot be estimated at this time. These costs would certainly drive the cost of the installation much higher. It must also be emphasized that the replacement power cost is based on replacing the loss of Fort Calhoun with OPPDs coal generation. If part or all of this power must be purchased from other utilities, these costs will be significantly greater.

The total radiation exposure for this task will be approximately 7,240 man-rem. The monetary value of such an exposure is difficult to estimate, but it is certainly substantial. Using the NRC criteria contained in 10CFR:50, Appendix I, the cost of the modification would be escalated by an additional $7,240,000. One major unknown is whether or not there will be sufficient craft labor available to undertake a project of this magnitude. Hundreds of qualified welders and other highly skilled personnel will be required and the availability of such craftsmen will depend highly on what other construction projects are in progress at the time this outage is taken.

C.7 Conclusions

The single motivating force prompting the feasibility study of restraining schemes, is a conclusion that the adequacy of the primary shield wall to withstand the high reaction loads from specified ruptures in the cold leg piping could not be drawn without resorting to lengthy and very expensive analyses with no certain confidence that final results would confirm such adequacy. This of course doesn't mean that the wall cannot accommodate the loads. Proceeding with such lengthy and expensive analyses is however, judged to be inappropriate at this time since fracture mechanics studies indicate that pipe ruptures which would engender the very high reaction loads (complete severance of the pipe and separation sufficient to result in a break area equal to twice the cross-sectional area of the pipe) will not occur as postulated. Rather, limited partial openings with total flow areas similar to those achievable by restraining the broken motion are more likely to occur.

Analyses of the vessel support reaction forces resulting from the breaks permitted by the conceptual restraint system previously described indicate that the maximum local reaction load on the biological shield wall is reduced to approximately 60% of the maximum local reaction load computed for the unrestrained break. Other loads are reduced even further. This reduced peak local load is less than the original design load.

Prior analyses[1] conducted in a different plant have indicated that the biological shield wall can be shown to withstand peak local loads which are twenty percent higher than the original design loads plus the asymmetric cavity loads. Hence, it is our engineering judgement that Fort Calhoun's biological shield wall, for the restrained break which is representative of a realistic maximum break in the pipe, would sustain all resulting loads. This judgement is predicated on the fact that the local peak loads at the supports in the radial and tangential direction are less than the original design loads and asymmetric cavity pressures are just a fraction of the cavity pressures resulting from full breaks (less than 20%).

It is therefore concluded that the plant is safe for realistic breaks. For the hypothetical full breaks, no definitive conclusion can be drawn at this time. Against this one must balance the potential impact on safety stemming from the addition of a restraining system.

The pipe restraint system would be totally unneeded for realistic breaks, and:

a) the addition of lugs would negatively influence the fatigue life, although it would still be acceptable,

b) the drilling of concrete necessary for the installation of the restraint structures would weaken the walls, particularly if rebar is accidentally cut,

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[1] St. Lucie Unit 1 - Docket No. 50-335, Reactor Coolant System Asymmetric LOCA Load Evaluation, March 3, 1980.

c) the bulk of material near the welds in the piping would render inservice inspection more difficult, and

d) the resultant exposure to workers from such or similar modifications would be in excess of 7,000 man rem.

The retrofitting of a restraining system can thus be viewed as possibly detracting rather than adding to the safety of the plant.

Due to the tremendous expense of this installation, both in terms of dollars and radiation exposures, Omaha Public Power District does not consider this to be a viable solution to the asymmetric loads analytical problem at the cold leg supports and the reactor cavity wall.

Table C-1

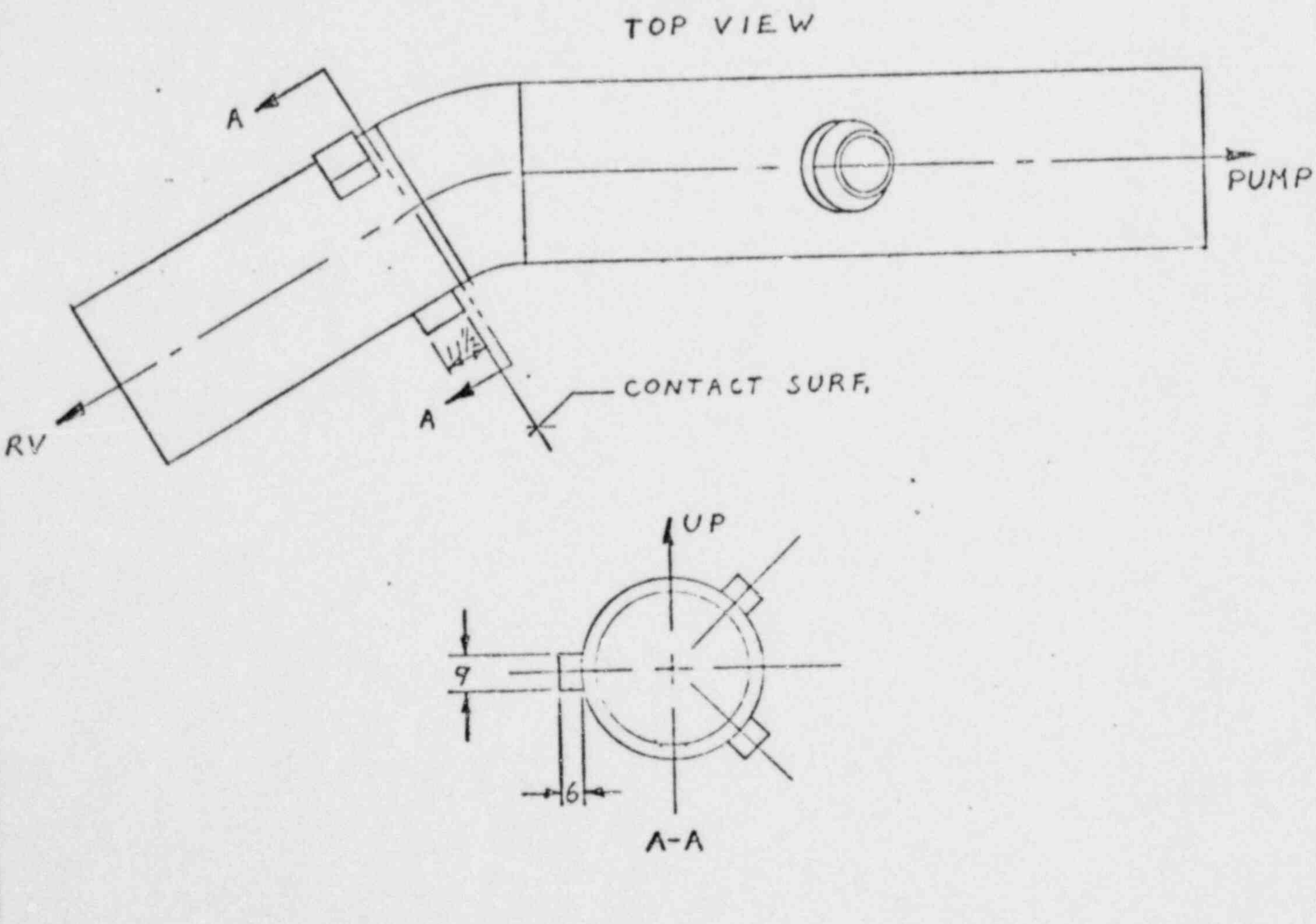
Fort Calhoun

Maximum Displacements & Break Opening Areas

RV Inlet Nozzle Guillotine

(inches, sq. inches)

Break Location	Discharge Pipe Motion		RV Nozzle Motion		Total Break Opening Area
	Radial	Axial	Radial	Axial	
RV Nozzle 1B	.59	.41	.49	.42	63.
RV Nozzle 2A	.53	.41	.49	.42	63.



PIPE RESTRAINT LUGS

FIGURE C-1

APPENDIX D

A PLAN FOR THE
FRACTURE ANALYSIS OF
FT. CALHOUN COLD LEG PIPING

The Omaha Public Power District is considering participation in the Westinghouse Owners' Group in order to resolve the RCS Asymmetric Loads issue through the use of fracture mechanics techniques. A complete report on the work regarding fracture mechanics analyses will be submitted to the NRC by December, 1980.