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Report
on
Design and Stress Evaluation
of
Failed Main Steam Safety Valve Nozzle

H. B. Robinson No. 2
Carolina Power and Light Co.

Report No. DC-67 May 23, 1970

Prepared for: U.S. Atomic Energy Commission
Division of Compliance
AEC Contract AT(11-1)-1658
Task-A
Parameter No. 69-70A

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← Attach #4 to be read

I. Introduction and Scope of Inspection

At the request of the Division of Compliance (Mr. W. C. Seidle, Senior Reactor Inspector Region II and Mr. D. L. Pomeroy, Technical Support Branch, CO-Hq), the writer attended a meeting held at Ebasco Services, Inc. offices in New York on May 15 to review the recent failure of a safety valve in the main stream line of the H. B. Robinson No. 2 plant at Hartsville, S. C. The writer accompanied Mr. W. C. Seidle, Senior Reactor Inspector and Mr. U. Potapovs, Metallurgical Engineer, both of the Region II offices at Atlanta representing the AEC in this review.

The Robinson-2 plant is a 663 MW(e) Pressurized Water Reactor (PWR) generating station being built for Carolina Power and Light Co. under a turnkey contract by Westinghouse Electric Co. Ebasco Services, Inc. is Designer and Constructor.

The failure of the safety valve nozzle has been assumed to be metallurgical and/or stress related and investigations have been pursued in these areas by Westinghouse and Ebasco respectively. A previous meeting (not attended by the writer) had been held at Westinghouse Pittsburgh and was concerned with preliminary metallurgical findings and planned investigative effort. The prime purpose of this meeting was to review further information on the metallurgical results and to obtain the results of Ebasco's design-analysis.

Mr. Potapovs is expected to report all metallurgical aspects of the failure. In this report, the author will document the meeting presentation related to design and summarize Parameter's evaluation of the safety valve connection in terms of stress levels presumed to occur at time of failure. In this later respect, the basis will be an independent estimate of stresses prepared by our Mr. W. J. Foley which is appended as Attachment 4.

I. Introduction and Scope of Inspection - Continued

Note: Preparation of an independent evaluation of stresses in general parametric terms was agreed upon with Mr. Seidle after the analysis summary presented by Ebasco during the meeting was not complete or conclusive. The Parameter analysis would include the effects of pressure and thermal discontinuities, and the possible superposed moment due to the safety valve discharging.

Other agenda items of the meeting include a general review of the incident, a discussion of the status of the review of the remainder of plant piping, the status of a "design fix", and the status of the investigation of the plant transient (primary system) due to the incident. These items are not considered within the scope of this report except to make some comments as to the criteria for a satisfactory fix.

The following personnel participated in the meeting held on May 15, 1970 at Ebasco Services, Inc., 2 Rector Street, N.Y. N.Y.:
(Titles or function may be approximate.)

Carolina Power and Light Co.:

H. Banks, Resident Engineer

Westinghouse Electric Co.:

T. Erion, Project Manager, Robinson-2

R. Cunningham, Research - Pittsburgh

Ebasco Services, Inc.:

J. Scarolla, Projects Manager (part time)

R. Pulito, Project Manager, Robinson-2

A. Rossi, Staff

I. Introduction and Scope of Inspection - Continued

Ebasco Services, Inc.: continued

B. Mazo, Metallurgist

L. Labriola, Supervisor - Stress Analysis

S. Boone, Stress Analyst

U.S. Atomic Energy Commission, Division of Compliance:

W. C. Seidle, Senior Reactor Inspector -
Region II, Atlanta

U. Potapovs, Metallurgical Engineer -
Region II, Atlanta

R. A. Lofy, Consulting Engineer -
Parameter, Inc., Elm Grove, Wis.

The writer's comments on the description and various details of the failure incident are included with the narrative report of the meeting in Section-III, Discussion of Inspection Items. Significant conclusions are reported in the Summary of Findings, Section-II following.

(Note: All notes made, computer printouts and calculations performed in connection with this assignment are maintained on file by PARAMETER and available for future reference as required.)

II Summary of Findings:

1. The safety valve nozzle was not analyzed for the load imposed by the jet reaction of the steam during discharge of the valve. The stresses due to this reaction can be expected to comprise a large fraction of the total maximum stress occuring when the valve "pops". If the valve popped, the resulting moment-reaction coupled with pressure end load and structural discontinuity stresses, can be considered a major contributor to the failure.

   If the valve did not pop, it is not possible to explain the overload failure in terms of pressure, weight, wind load and structural pressure discontinuity stresses. Based on estimated temperature gradients, thermal discontinuity stresses across the failed area turned out to be nominal.

   Please refer to Attachment #4 for a summary of stresses calculated in the trail analysis performed by Parameter, Inc., and conclusions regarding the probable stress related basis for the failure.

2. It has been determined that an axial tensile stress on the order of 60,000 psi can exist in the nozzle wall under the steam discharging condition.
   (Calculation of this stress requiried making some assumptions regarding the reaction forces as described in Attachment #4.)
   This approximate stress level, without a stress concentration factor is sufficiently high to be a prime contributory cause of failure without major metallurgical defects being present.

   The Mill Test properties of the material have been quoted at 48,500 psi Yield and 75,700 psi Ultimate. Specification minimums for this material are 35,000 psi and 60,000 psi respectively. The margin in material strength available and the uncertainties of assumptions made in the trial analysis do not preclude the possibility that a minor metallurgical defect could have been a contributory factor - assuming the steam discharge mode.

I. <u>Summary of Findings</u>: continued

3. Although the Power Piping Code (B31.1.0-1967 assumed to apply) does not appear to treat safety valve discharge forces directly, it is the opinion of the writers that omission of this force in establishing the design is a violation of the general criteria of this code.

   (Para. 101.5 covers "Dynamic Effects" and para 101.5.1 "Impact" specifically in stating that "Impact forces caused by all external and internal conditions shall be considered in the piping design."

The valve discharge would most certainly be considered a dynamic effect and can be classified as an impact force.

III. Discussion of Inspection Items

In introducing the meeting attendees to the background and circumstances under which the steam line safety valve failed, Mr. T. Erion of Westinghouse presented a brief description of the plant arrangement and tests in progress at the tme of failure.

Each of the three main steam lines A, B and C (or 1, 2 and 3) from the Nuclear Steam Supply System (NSSS) contain one power operated blow-off valve and four (4) spring loaded safety valves set to relieve at 1075, 1105, 1125 and 1140 psig respectively. These valves are located outside of the containment and upstream from the main steam isolation valves, which were closed, and check valves. Exhibit-B shows the relative position of these valves schematically as presented to the group on the blackboard. The failed nozzle was associated with the highest setting safety valve (1140 psig) located in line C(1) as indicated on Exhibit-B. The safety valve was identified as a Crosby Style No. HCU-65W (Ref. 1). Two sizes are used in the system , 6" (inlet) by 10" (outlet) and 6" x 8". The failed valve was believed to be a 6" x 8" as stated by Mr. Erion.

(Note: Inquiry Memoranda (References 1 and 2) were made available to the writer prior to the meeting and contain pertinent data regarding test conditions (pressures and temperatures) before and after the incident, and records of prior inspections.)

The Robinson plant was in the last stages of hot functional tests at the time of the incident. Mr. Erion explained that the valve testing was left as one of the last items in their test program. Crosby personnel had been called in for the tests to make any adjustments to valve settings that might be required. They had completed tests on steam lines A(1) and B(2) and were working on C(3) at the time of the failure.

III. Discussion of Inspection Items: continued

The test procedure was described approximately as follows: With steam pressure below the valve discharge setting (say 900 psig) a pneumatically operated lift device is attached to the valve and enough pressure applied to simulate the differential between the actual steam pressure and the blow-off pressure. The pressure to the lift device was applied by means of a nitrogen bottle and regulator. The object is to add just enough pressure to get the valve to "simmer" or leak steam. This is the calibration point. However, it is characteristic of the valve to "pop" wide open when only slightly higher than "simmer" pressure is reached. As an example of the delicate balance, between "simmering" and "popping", of the eight (8) valves previously tested by experienced Crosby personnel in this series, three (3) simmered only, but five (5) popped.

The writer asked how long the system was at elevated temperature and pressure prior to the failure. Mr. Erion replied that the hot functional tests had been in progress with the steam lines heated for nine (9) days.

> This steady state condition precludes the need to consider temperature and pressure transients in our evaluation of the failure. However, steady state conditions do not imply that uniform temperatures exist in the area of the valve to header connection because of the termination of the insulation and change in sections and surface areas at this point.

Mr. Erion went on to explain how, immediately after the incident, an investigation team was set up to conduct the:

1) Design review,

2) Metallurgical investigation,

and 3) To evaluate effects of the transient on the primary system.

III. Discussion of Inspection Items: continued

The writer asked whether an estimate of the temperature of the valve was available. Ebasco personnel indicated that one could put his hand on the valve in the upper area, but they had no data on the overall temperature.profile or the specific temperatures in the transition area adjacent to the nozzle. It was pointed out that actual in-service surface temperatures of these valves would be relatively easy to obtain by "Tempil" stick or thermocouple.

> Valve body temperature could be an important consideration in analysis of the failure area. For our trial analysis of Attachment #4, we have estimated a number of temperature profiles to establish a trend of thermal stress versus temperature gradient and to determine its significance.

The main steam header was described as being lagged with canned Unibestos type insulation. Study of photos of the installation showed the insulation as terminating near the top of the taper at the lower end of the valve body. The fabrication design of the valve to header joint was described by a layout displayed during the meeting. On the basis of notes and sketches made during the meeting, this design has been drawn approximately as displayed in our Sketch-2, Attachment-2.

The weight of the valve was given as 950 lb. without the stack and 1300 lb. with the stack. Its general arrangement with respect to the steam line is shown on Sketch-1, Attachment-1. There is no external support to either the valve body or the elbow-stack assembly.

The header and valve assembly was hydro-tested at 1356 psi during a 4½ hour pressurization cycle according to Mr. R. Pulito of Ebasco. This particular valve did not weep during hydro. (Valve presumably blocked shut at test pressure.)

III. Discussion of Inspection Items: continued

(While this report is primarily concerned with the design review aspects of the failure, discussion of the transient will be reported and observations made to the degree that the writer participated in this discussion.)

In discussion of the progress of the test of the valve in question, it was established that the pneumatic lift device was being used and they were starting to go up in pressure. It was the reported opinion of test crew members that the valve did not "pop". However, there seems to be conflicting opinion in this respect. Observers report hearing two distinct sounds - one could be the valve popping, the second could be the escape of steam upon rupture of the nozzle. On the other hand, the first sound could have been associated with the break in the nozzle followed by the discharge report of steam. It was stated by Mr. Cunningham of Westinghouse that examination of the valve showed grease in the area of the valve stem and paint in the exhaust section which did not appear to have been scrubbed away by exhausting steam. (This valve was reported not to have simmered during previous tests.) Thus the feeling that the valve did not pop. Mr. Cunningham did point out however, that the grease was not in the direct patn of the steam and the general appearance was not a great deal unlike that of other valves which had popped.

It is the writer's opinion that, at best, this evidence as presented is inconclusive. If the valve popped and failed soon afterwards, it would not have experienced a great deal of steam flow. If conclusions are made on the basis of these indications in the future, they should be developed from a more thorough study of the history of operation of this valve and comparison with other valves of known usage, and confirmed possibly with tests under controlled conditions. Whether or not the valve popped is of course an important consideration in analysis of the cause of failure, particularly if predominantly stress related. Conclusions as to this probability can be drawn from the trial analysis presented in Attachment No. 4.

III. Discussion of Inspection Items: continued

The header and transition piece (nozzle) were designed by Ebasco Services and fabricated by B. F. Shaw Co. The nozzle was made from A106 Gr. B Schedule 80 seamless pipe. The weld between the valve body and the nozzle in the reduced section (Schedule #40) was made with the aid of a backing ring left in place. This weld was made by field personnel under Ebasco's construction contract. The field weld was not stress relieved.

> Note: While Ref. 1 reports stress relieving in accordance with code requirements, this section, being under 3/4" wall thickness, would not require stress relief.
>
> It is difficult to predict the magnitude of residual stresses due to welding in a case like this. An observation can be made however that the hoop restraint or pinching effect of the residual stresses in the weld tends to add to the pressure and thermal discontinuity stresses already present at severe changes in section in the failure area. The backing ring, which is assumed fused to the weld provides even further restraint under pressure and temperature.

Mr. Cunningham of Westinghouse went on to report the results of their metallurgical investigation to date. He explained that he had been called in from the Westinghouse Research organization to work with the project group as a more or less independent consultant. The character of the failure was described by Mr. Cunningham at the board essentially as reconstructed on our Sketch-3, Attachment-3. From a design-analysis point of view, it suffices to say that he described the failure as a typically tensile break. and reported that no abnormalities were yet found in the physical properties of the material.

III. Discussion of Inspection Items: continued

They believe that a crack started from the inside (not confirmed) at initiation of failure from the west edge which progressed symetrically about the E-W center line to the east edge. (See Attachment-3). The inner edge of the break followed the transition line between the Schedule #40 diameter and the tapered section, and thus there was no opportunity to establish the tool radius of this corner. However, Westinghouse plans to measure a tool radius for the adjacent machined surfaces which might be an indicator to that which existed at the transition line. Some necking-down of the failed section was observed.

Westinghouse reported that single wall radiographs showed no rejectable defects. Metallographic examination showed only some normal longitudinal stringers in the pipe.

The preliminary conclusion by Westinghouse is that there are no materials problems and that an overload type of failure is indicated. The final metallurgical report was expected to be issued within a few weeks of the meeting date.

> Questions and answers during the discussion of the failure revealed a consensus that the nozzles or transition pieces were machined as detail parts in a lathe (vs. boring after assembly to the header) and that the Schedule #40 counterbore and transition taper were made in the same setup. If this is the case, as would be expected, we should not find any offset or eccentricity between the counterbore and taper which could act as an additional stress condentration factor and discontinuity. It was asked whether other nozzles could be inspected to verify this fact. Mr. Banks (C. P. & L.) said it was not possible to view this area adequately with the valves welded in place. However, it does seem possible to the writer that some in-situ inspection could be performed by removing the valve mechanisms and viewing with a boroscope or similar device. If it is decided to leave the other valves in place, such an inspection to reveal any incipient flaw might be well warranted.

III. Discussion of Inspection Items: continued

During the afternoon session, Ebasco stress analysis personnel presented the results of their design-analysis as recorded on Exhibit-A attached. The stresses as displayed initially on the board by Mr. S. Boone are shown in the original columns. Revisions to these numbers, as evolved from modification of the assumptions upon which the analysis was based by Mr. Pulito and Mr. Labriola are offset and shown in parentheses. The meaning and applicability of both the original and revised numbers can best be explained by summarizing the results of somewhat probing inquires by the writer and responses obtained as follows.

As the mode of failure appeared to be related to longitudinal loadings, Ebasco tabulated only longitudinal stresses at 900 psig, 1140 psig and 1356 psig. The 900 psig valve was the approximate pressure at the time of failure, 1140 psig was relief setting of the valve and 1356 psig the previous hydro-test temperature. The stresses at 900 psig and 532°F operating pressure are of greatest interest to us in this evaluation. The primary longitudinal stresses were due to internal pressure, weight of the valve, and a wind loading of 30 mph. estimated at the time of failure. The primary axial stress is tensile and its constituents self explanatory. Two secondary stresses (bending through the wall thickness) were calculated:

1) "Bending Stress Due to Eccentricity" (offset of mean diameters of walls at change in section)

and 2) "Bending Stress Due to Step in Thickness" (this is a pressure discontinuity stress at the change in section of the wall).

The mathematical model for the "original" stresses is shown on Exhibit-A and depicts an abrupt change from the Schedule #40 (.28") wall section of the 6" diameter nozzle to a wall section of approximately 1½" in the valve. This treatment with a 90° step at the change

III. Discussion of Inspection Items: continued

in section is harsh and the analysis should be conservative. Bending stresses are added arithmetically and summed with axial tensile stresses to arrive at a conservative maximum stress of 24,070 psi (the original case).

> As the opposing effect (opposite sign) of the bending stresses due to eccentricity and change in section are neglected and the maximum eccentricity at an abrupt change in section assumed, this value of stress might be expected to be conservatively high. Yet the value is sufficiently below the Mill Test Yield and ultimate values of the material (48,500 psi and 75,700 psi respectively) that a failure of the type observed would not be expected to arise from these axial stress levels. It is pointed out however that a third contributor to the axial bending stresses will be the thermal discontinuity stress due to bulk temperature gradient along the nozzle and valve body walls. This gradient results from the termination of insulation at the valve and the greater heat dissipation capability of the valve volume and surfaces.

After the original stresses as described above were presented, Mr. Pulito stated that he thought the stresses due to step in thickness were unrealistically high as far as the conditions at the point of failure were concerned. Because the failure occurred at the transition between the Schedule #40 (.28") and Schedule #80 (.43") sections of the nozzle, it was felt that only this change in thickness should be considered for the "Bending stress due to step in thickness." By slide rule calculations they determined that this stress (the pressure discontinuity) should be approximately 44% of the value given in the original presentation. Thus, bending stresses due to step in thickness were reduced to 44% of their original value for all three pressure cases and new totals were substituted. These revised numbers are shown in parentheses on the chart of Exhibit-A. The derivation of the .44 factor was not explained. In any case the revised chart is now inconsistent and incomplete because we have: (using their methods)

III. Discussion of Inspection Items: continued

1) Bending stresses due to eccentricity between the Schedule #40 (.28") and the valve (1.5") walls

added

to 2) Bending stresses due to step in thickness (pressure discontinuity) between the Schedule #40 (.28") and Schedule #80 (.43") walls,

but missing are:

3) Bending stresses due to eccentricity between the Schedule #40 and Schedule #80 sections

and 4) Bending stresses due to step in thickness between the Schedule #40 and valve wall.

Ebasco stress personnel agreed with the writer's comments that the stresses at the two changes in section could not be separated due to their axial proximity (about ½") and that a nearly complete interaction of the stress components listed above must be expected to exist.

Because the eccentricity stress is not large; however, the analyses are not entirely meaningless for comparison purposes. The original numbers can be taken to represent a harsh analysis or/and upper limit of secondary stresses. On the otherhand, the revised numbers could be taken as a lower non-conservative limit thus bracketing the probable actual case. In neither case are thermal stresses considered.

The writer asked Ebasco personnel whether they had considered thermal stresses. It was stated by Mr. Labriola that thermal stresses were not expected to be high and were not calculated. The point was made by the writer that even though thermal stresses were predicted to be low, they were present and because this was a failure analysis should be considered. In this case establishing that the design met code requirements and allowable stress levels might not be enough to establish the contribution of real stresses to the failure.

III. Discussion of Inspection Items: continued

It was reported that no stress concentration factors were used in the Ebasco analyses.

In view of the sharp corners apparent at the changes in section, especially at the point of failure, omission of SCF's in analyzing for the cause of failure does not seem realistic. Revise wording

From the discussion of the subject, the writer drew the conclusion that only a Code pressure analysis had been performed in the original design. In addition, Ebasco stated that an analysis had also been made for seismic conditions. It was clearly established, in response to questions by the writer and Mr. Potapovs, that the joint nozzle connection was not analyzed for the blow down case. Mr. Pulito said they were considering supports for the valves, but it was not clear whether these were contemplated before the failure or after-the-fact fixes. He stated that in any case the final installation would meet all requirements.

The ommission of the bending moment due to valve blow-off has to be considered a serious deficiency in the design-analysis. The jet reaction forces during blowdown are large and in the case of this design, acting on a fairly long lever arm. If the valve popped prior to failure, the moment superposed on the pressure loads would have to be considered as a likely major contributor to the failure. Conversely the fact of failure and relative stress levels existing under steady state conditions vs. blow-off might be decisive in concluding whether the valve popped or not. Further evidence to support either case will be essential to final conclusions.

A design fix for the valve connection is being considered by Ebasco and Westinghouse. They indicated that a number of different approaches were being studied and they were not yet ready to discuss these in detail. From the conversation, it was obvious that one modification would involve removing the short 6" Schedule #80 pipe nozzle and welding the valve directly to the steam line (and rein forcement plate) with a heavy section weld in the area of the 45° taper on the bottom of the valve.

III. Discussion of Inspection Items: continued

Mr. Erion stated that they hoped to decide on the design modification within the next week. They are trying to have field work completed by June 7. Their position is that a design modification can be developed and work proceed without having conclusively learned the cause of the original failure.

One cannot argue that a new design can be developed without learning why the original failed, but from an AEC-Compliance point of view, the cause would remain important. There are many other connections of this type in this plant and possibly more in other plants designed by Ebasco or other A/E's.

In any event, a revised design or any modification to the existing design should be subjected to a rigorous design-analysis. Beefing up the connection might not solve all conditions of overstress experienced and might further introduce new factors. It would be appropriate that the AEC-Compliance review the new design and analysis both to confirm its adequacy and to provide a further reference for evaluation of the original failure.

Mr. Siedle emphasized the need to know the cause of failure even if the fix involves a major change to the design. He emphasized the effects on primary systems as being of real concern as a result of this type of failure.

Mr. Pulito described Ebasco's program to review all safety valve and piping connections that might be considered similar to the safety valve nozzle in the Robinson-2 plant. The following quantities of connections had been identified for review:

a) 24 weld connections similar to the safety valve (all with reduced thickness sections),

b) 18 flanged connections,

and c) 40 other flanged, screwed or socket-welded connections.

III. Discussion of Inspection Items: continued

He said they were looking at all reduced sections to determine if they meet design criteria. Mr. Pulito stated that they were not in a position to discuss other plants at this time.

The writer would like to point out the evaluation of pipe or valve connections to meet Code pressure and temperature criteria might not be good enough to establish reliability. The failed safety valve connection is an excellent case in point. The joint was apparently sized for obvious pressure and weight, and possibly seismic and wind loadings, but the most severe loading condition of valve popping was not considered in the total analysis. The codes, while providing specific rules and formulae for pressure design, generally leave the evaluation of imposed loads to the designer and define the requirements for their evaluation only in general terms. It is encumbent upon the designer to evaluate each case individually and provide assurance that the design meets its functional requirements whether the criteria therefore are specifically provided by the applicable codes or not. A further review of Ebasco's work in their evaluation of other connections should provide the AEC-Compliance with the type of information necessary to establish a level of confidence in the critical plant systems.

Some discussion was centered about the fact that no one in the group, particularly the Ebasco personnel with both nuclear and fossil steam plant background, had experienced or knowledge of a similar plant failure. Mr. Siedle asked whether safety valves in fossil fueled plants were similar. Ebasco personnel explained that, while generally similar in mounting arrangement on steam drums or lines, because the fossil plants operate at a higher temperature and pressure the pipe connections were generally of heavier wall and/or in higher strength alloy materials. From the discussion, it could be concluded that these particular parameters of this design and its configuration were probably unique to a nuclear plant.

III. Discussion of Inspection Items: continued

The above comments are important in categorizing the failure or assessing its probability of occurrence on basis of other plant experience. A nozzle connection designed for higher steam pressures and temperatures would have a greater wall thickness, and/or use higher strength alloy materials. Thus, it would inherently possess a greater margin of strength to resist externally imposed loads - such as the steam discharge reaction.

Conversely, when designing for comparatively low steam saturated steam pressures and temperatures in nuclear plants, relatively thin walls can be used in low alloy materials. Therefore, comparably high reaction loads will cause a much higher stress and larger percentage of the total stress in the lighter sections. We think that this relationship might have been an important factor which resulted in the subject design being marginal for large discharge loads. The analyses of Attachment #4 show how the discharge forces are predominant in the total stress picture.

As the last agenda item of the meeting, Mr. Erion of Westinghouse explained their approach to reviewing the effect of the transient which resulted from the valve nozzle failure on the primary system.

He expained that the pressure and temperature history during the transient were very well documented by facility recorder charts and data taking which was started by operating personnel soon after the start of the transient. The primary system experienced a 213°F temperature drop during a period of 63 minutes. The writer asked whether this was the actual transient experienced by all primary system components or an average coolant temperature change. Mr. Erion said that for all practical purposes this temperature cycle was representative of all parts of the system. He said they had good natural circulation after the pumps were stopped - better than expected. He stated further that the temperature response of the system correlated well with that predicted in earlier theoretical computer analyses.

III. Discussion of Inspection Items: continued

They had initiated a program to determine the effect of the transient on all major components. Designers of the vessel, pressurizer, steam generators, pumps, etc. were given the transient data and asked to respond as to its effect on their components. Mr. Erion reported that most of the groups contacted had responded and no problems were identified.

The report of the transient effect on the primary system referred to above was brief and more in the form of a progress report than a technical account.

It is of course undesireable to experience transients in components which will reduce their remaining usage, particularly early in the life of a plant. The effect of the transient on usage is not obvious nor can one categorically define its effect on all system components. Each area of high stress and thermal related usage must be looked at individually. It is understood that the AEC-Division of Reactor Licensing will be reviewing the applicants evaluation of the transient effect on the entire primary system. The writer wishes here merely to endorse the AEC position in assuring that the system has not suffered severe damage by making a thorough review of the reported transient effects.

IV. References:

1. Inquiry Memorandum - Carolina Power and Light Co. (H. B. Robinson No. 2) License No. CPPR-26 Docket No. 50-261, W. C. Seidle, SRI, CO-II to J. P. O'Reilly, Chief, Inspection and Enforcement Branch, CO-Hq dated April 29, 1970

2. Inquiry Memorandum - Carolina Power and Light Co. (H. B. Robinson No. 2) License No. CPPR-26 Docket No. 50-261, W. C. Seidle, SRI, CO-II to J. P. O'Reilly, Chief, Inspection and Enforcement Branch, CO-Hq dated April 30, 1970

V. Appendix:

BY.......... DATE.......... SUBJECT.......... SHEET NO.......... OF..........

CHKD. BY.......... DATE.......... JOB NO. 69-70A

DC-67

EXHIBIT- A

STRESSES AS EXHIBITED AT 5-15-70 MEETING
AT EBASCO, N.Y.

CODE ALLOWABLE STRESS	-15000 PSI	
YEILD STRENGTH — —	40500 PSI	MILL TEST VALUES
ULTIMATE STRENGTH —	75700 PSI	

PRESSURE	900 PSI	1140 PSI	1356 PSI
PRIMARY STRESS			
LONG. STRESS DUE TO PRESSURE	4660	5900	7010
LONG. STRESS DUE TO WEIGHT	960	960	960
LONG. STRESS DUE TO WIND	750	750	750
TOTAL PRIMARY	6370	7610	8730
SECONDARY STRESS			
BENDING STRESS DUE TO ECCENTRICITY	2650	3350	4000
BENDING STRESS DUE TO STEP IN THICKNESS	15050 (6600)	19060 (8400)	22370 (9900)
TOTAL SECONDARY	17700 (9250)	22410 (11750)	26670 (13900)
PRIMARY + SECONDARY	24070 (15620)	30020 (19360)	35400 (22630)

(INCOMPLETE)

69-70 A
DC-67
EXHIBIT - B

Main Steam Line
and
Safety Valve
Schematic

(to be completed)

1 of 21

Stress Analysis
of
Failed Main Steam
Safety Valve Nozzle

H. B. Robinson No. 2
Carolina Power and Light Co.

Attachment No. 4
To Report DC-67

May 23, 1970

Prepared for: U.S. Atomic Energy Commission
Division of Compliance
AEC Contract AT(11-1)-1658
Task A
Parameter No. 69-70 A

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Consulting Engineers
Elm Grove, Wisconsin

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Introduction

The purpose of this attachment is to make a theoretical stress analysis of the failed safety valve nozzle in order to determine tentatively what loading conditions existed at the time of failure.

Only the steady state hot operational condition at 900 psig and no load is investigated. Thermal stresses are computed for four (4) arbitrary temperature distributions which are intended to bracket the actual thermal condition. The effect of possible popping is analyzed. Results are summarised in convenient form for evaluation of the report which will be submitted by the licensee.

Assumptions, the analytical model, assumed temperature distributions, computer runs and analytical methods are described. Tentative conclusions are made on the basis of incomplete information available at this time.

Assumptions

Conclusions

BY H. Foley DATE 5-24-70 SUBJECT SHEET NO. 6 OF

CHKD. BY DATE Attachment No. 4 JOB NO.

To Report DC-67

Summary

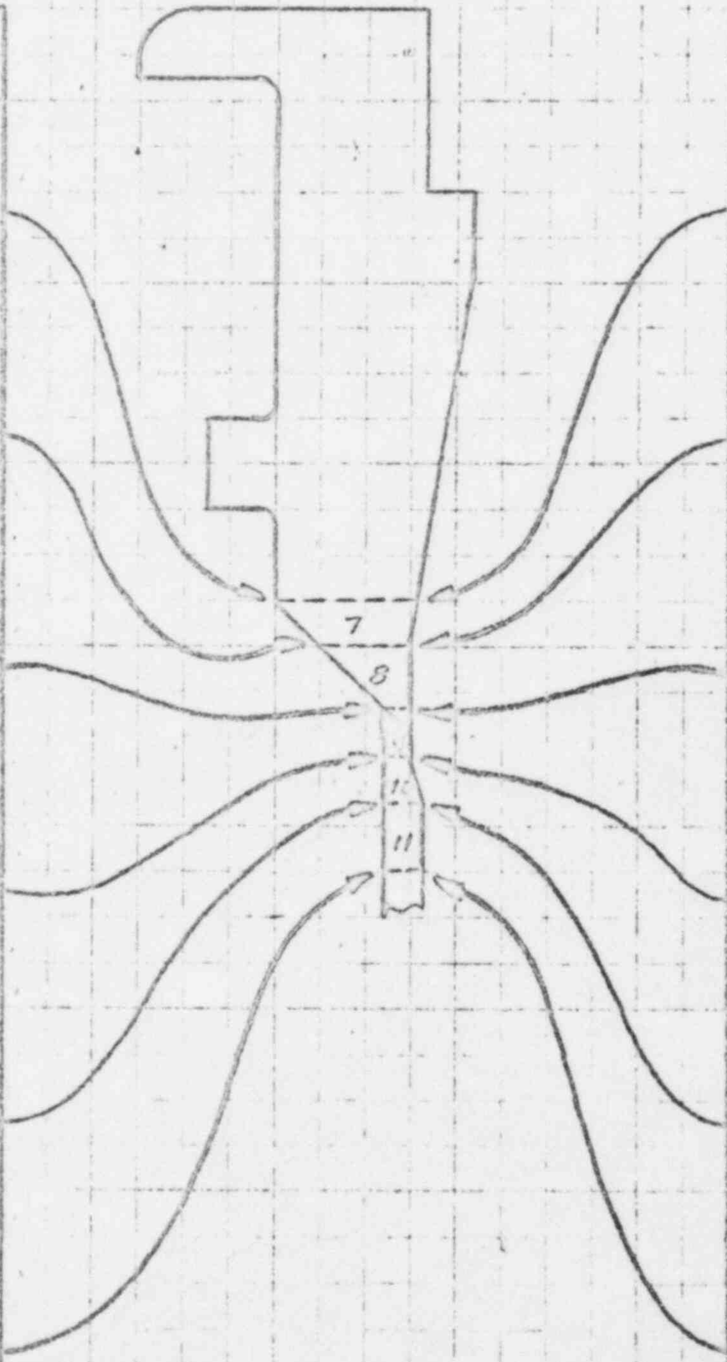
BY W. FOLEY DATE 5-23-70 SUBJECT ATTACHMENT NO. 4 SHEET NO. 7 OF

CHKD. BY LSD DATE 5-23-70 TO REPORT DG-67 JOB NO.

SUMMARY OF LONGITUDINAL STRESS WITHOUT STRESS CONCENTRATION FACTOR

OUTSIDE

RUN NO.	σ_ℓ PSI
1	- 1033
3	3821
5	3333
7	3031
9	841
1	- 1733
3	2081
5	1806
7	947
9	- 567
1	3809
3	9511
5	7858
7	—
9	—
1	6673
3	7661
5	7444
7	7521
9	7069
1	4538
3	3356
5	3743
7	4690
9	4620
1	3753
3	2795
5	3150
7	3881
9	3928



INSIDE

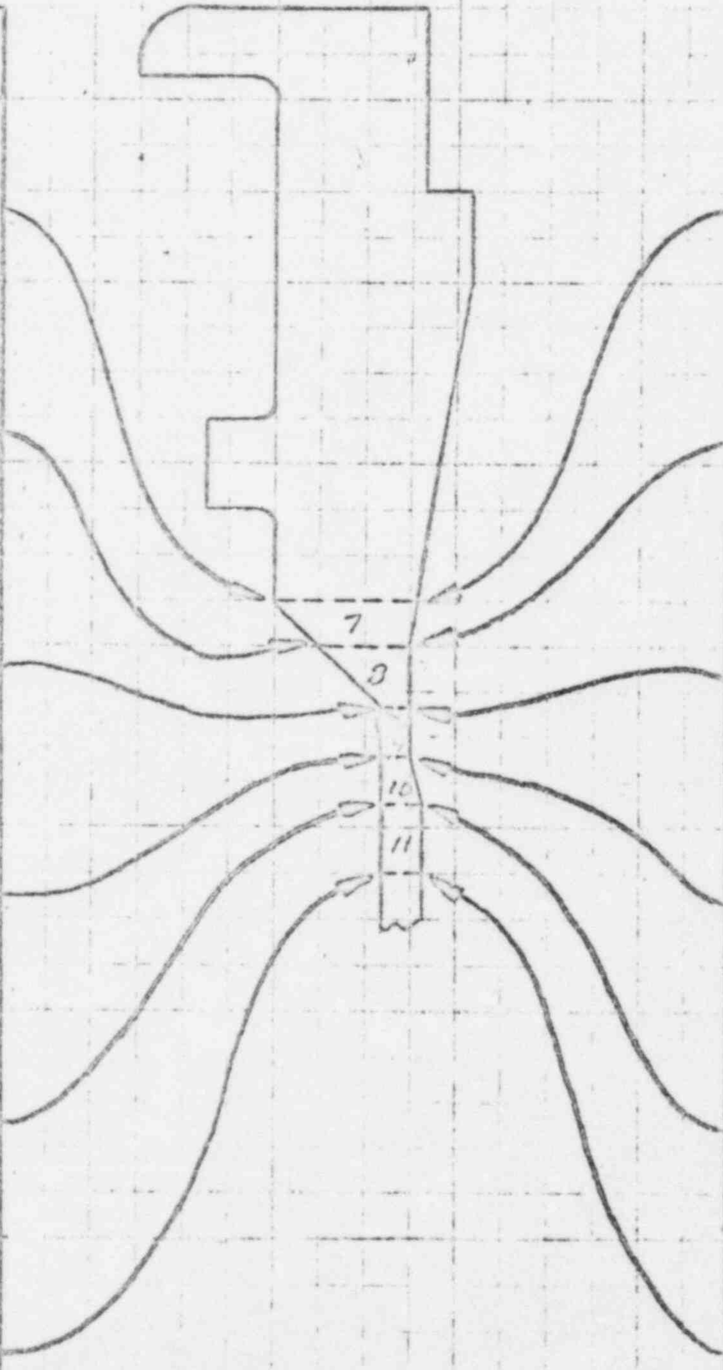
RUN NO.	σ_ℓ PSI
1	- 2372
3	- 2476
5	- 1798
7	- 1656
9	503
1	5166
3	- 448
5	427
7	[illegible]
9	—
1	5502
3	- 199
5	1459
7	4266
9	4961
1	2662
3	1656
5	1873
7	—
9	—
1	1044
3	2227
5	1057
7	892
9	963
1	1627
3	2702
5	2432
7	1701
9	1655

BY W. FOLEY DATE 5-28-70 SUBJECT ATTACHMENT NO. 4 TO REPORT 26-67 SHEET NO. 8 OF
CHKD. BY RSD DATE 5-28-70 JOB NO.

SUMMARY OF TANGENTIAL STRESS WITHOUT STRESS CONCENTRATION FACTOR

OUTSIDE

RUN NO.	σ_t PSI
1	1532
3	4676
5	5083
7	5572
9	3414
1	1834
3	4402
5	3983
7	4286
9	2864
1	5261
3	9347
5	8067
7	—
9	—
1	7676
3	10302
5	7529
7	8100
9	7868
1	7497
3	8342
5	8077
7	7701
9	7587
1	6854
3	6783
5	6811
7	6905
9	6879



INSIDE

RUN NO.	σ_t PSI
1	2558
3	- 1666
5	- 957
7	- 1407
9	715
1	2591
3	1917
5	2106
7	—
9	—
1	5770
3	6486
5	6162
7	5069
9	5424
1	6497
3	8500
5	7857
7	—
9	—
1	6447
3	6803
5	7522
7	6562
9	6490
1	6157
3	6781
5	6595
7	6251
9	6197

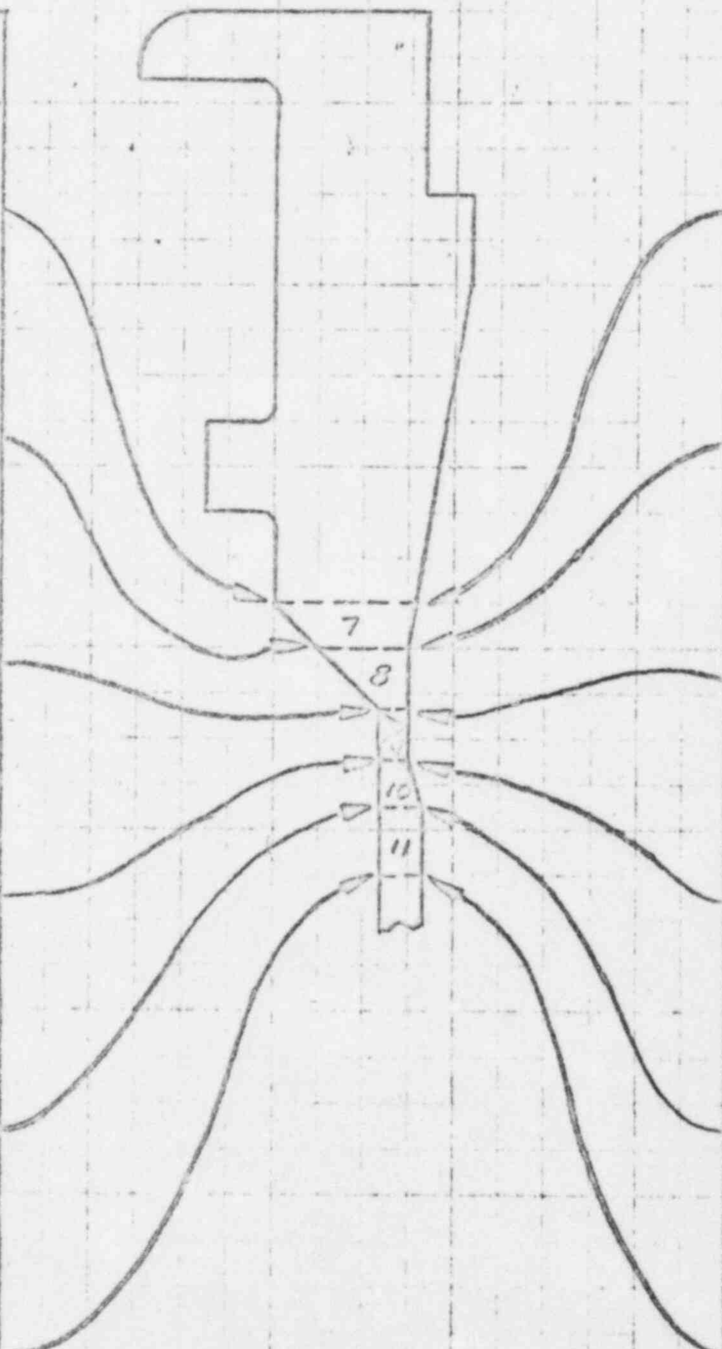
BY M. FOLEY DATE 5-23-70 SUBJECT ATTACHMENT NO. 4 SHEET NO. 9 OF

CHKD. BY RSD DATE 5-23-70 TO REPORT DC-67 JOB NO.

SUMMARY OF STRESS INTENSITY WITHOUT STRESS CONCENTRATION FACTOR

OUTSIDE

RUN NO.	S PSI
1	2565
3	4676
5	5083
7	5672
9	3414
1	3567
3	4402
5	3983
7	4286
9	3431
1	5261
3	9511
5	8069
7	—
9	—
1	7676
3	10302
5	9529
7	8100
9	7868
1	7477
3	8342
5	8079
7	7701
9	7587
1	6854
3	6703
5	6811
7	6905
9	6879



INSIDE

RUN NO.	S PSI
1	3455
3	1576
5	1988
7	786
9	1616
1	5066
3	2019
5	3045
7	—
9	—
1	6671
3	7356
5	7047
7	5956
9	6334
1	7307
3	9402
5	8757
7	—
9	—
1	7369
3	8703
5	8423
7	7442
9	7390
1	7057
3	7681
5	7775
7	7151
9	7097

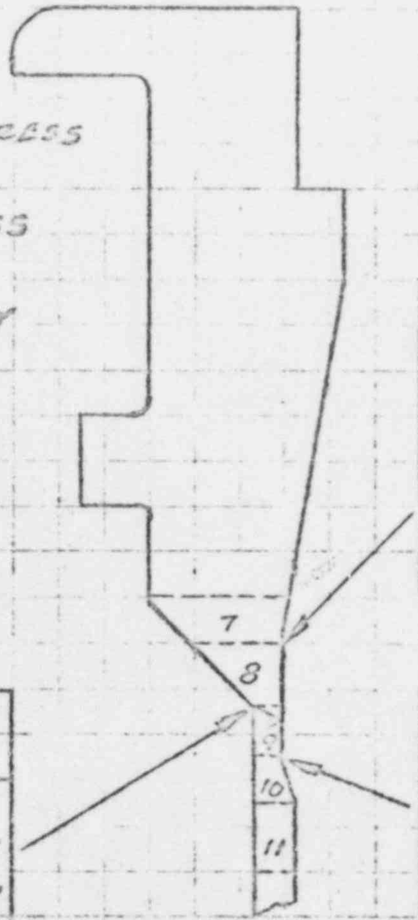
SUMMARY OF STRESS AND STRESS INTENSITY WITH STRESS CONCENTRATION FACTOR

σ_l —— LONGITUDINAL STRESS

σ_t —— TANGENTIAL STRESS

S —— STRESS INTENSITY

A STRESS CONCENTRATION FACTOR OF 1.5 HAS BEEN ASSUMED FOR THE THREE LOCATIONS SHOWN.



RUN NO.	σ_l PSI	σ_t PSI	S PSI
2	6249	4036	7149
4	- 142	1828	2723
6	- 1471	2216	3116
8	3421	1506	4321
10	5030	2876	3776

RUN NO.	σ_l PSI	σ_t PSI	S PSI
2	5714	5134	5714
4	14266	10075	14266
6	11787	8557	11787
8	7577	5349	7577
10	6534	5197	6559

RUN NO.	σ_l PSI	σ_t PSI	S PSI
2	3966	6185	7005
4	2904	8050	8950
6	2810	7440	8340
8	2693	5953	6853
10	5372	6060	6960

Description of Computer Runs

Run No.	Date	Description
1	5-21-70	DC67 at 900 psig and 70 F without SCF
2	"	" " " " " " with SCF
3	"	" " " " " Temp 1 without SCF
4	"	" " " " " " with SCF
5	"	" " " " " Temp 2 without SCF
6	"	" " " " " " with SCF
7	5-22-70	" " " " " Temp 3 without SCF
8	"	" " " " " " with SCF
9	"	" " " " " Temp 4 without SCF
10	"	" " " " " " with SCF

Note:
1. Computer input sheets and printouts are maintained in file by Parameter, Inc.
2. Temperature conditions "Temp 1" through "Temp 4" are described on Pages 17 through 19.
3. Stress concentration factors are described on Page 10.
4. The computer program is described on the following page.

BY M. Foley DATE 5-24-70 SUBJECT Attachment No. 4 To Report DC-67 SHEET NO. 12 OF

CHKD. BY DATE JOB NO.

Description of Computer Program

Finite Cylinder Stress Program
A.O.Smith Corporation
Data Systems Division
Library No. 05120

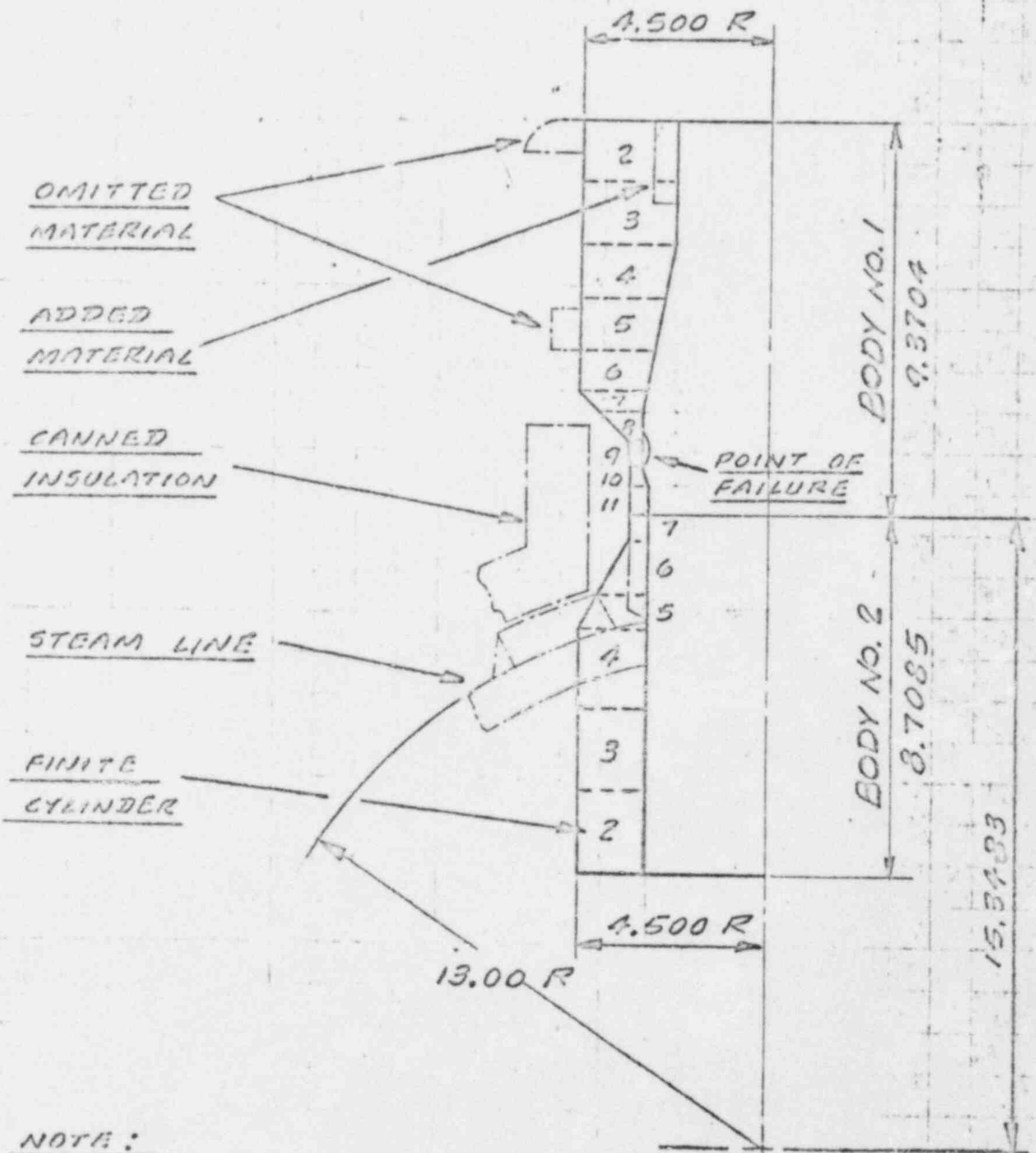
This computer program is used for determining pressure vessel stresses in accordance with the ASME Nuclear Code. Stresses and motions are printed out for combinations of internal and external pressure, mechanical loads, and axial and radial temperature gradients.

Metal temperatures and thermal moments taken from printouts of the Generalized Heat Flow and Thermal Moment programs are used as computer input. The effects of local flexibility are introduced readily at the analyst's option. Interaction with bodies such as tubesheets, hemispheres and bolted closure heads is analysed by using the Simultaneous Equation Program to solve compatibility equations of two or more bodies for which influence coefficients have been determined.

BY .... DATE 5-22-70 SUBJECT ATTACHMENT NO. 4 TO REPORT DC-67 SHEET NO. 13 OF ....

CHKD BY RD DATE 5-23-70 JOB NO. ....

ANALYTICAL MODEL OF SAFETY VALVE NOZZLE



NOTE:
FOR EXPLANATION, REFER TO FOLLOWING PAGE.

SCALE: $\frac{1}{4}$ X SIZE

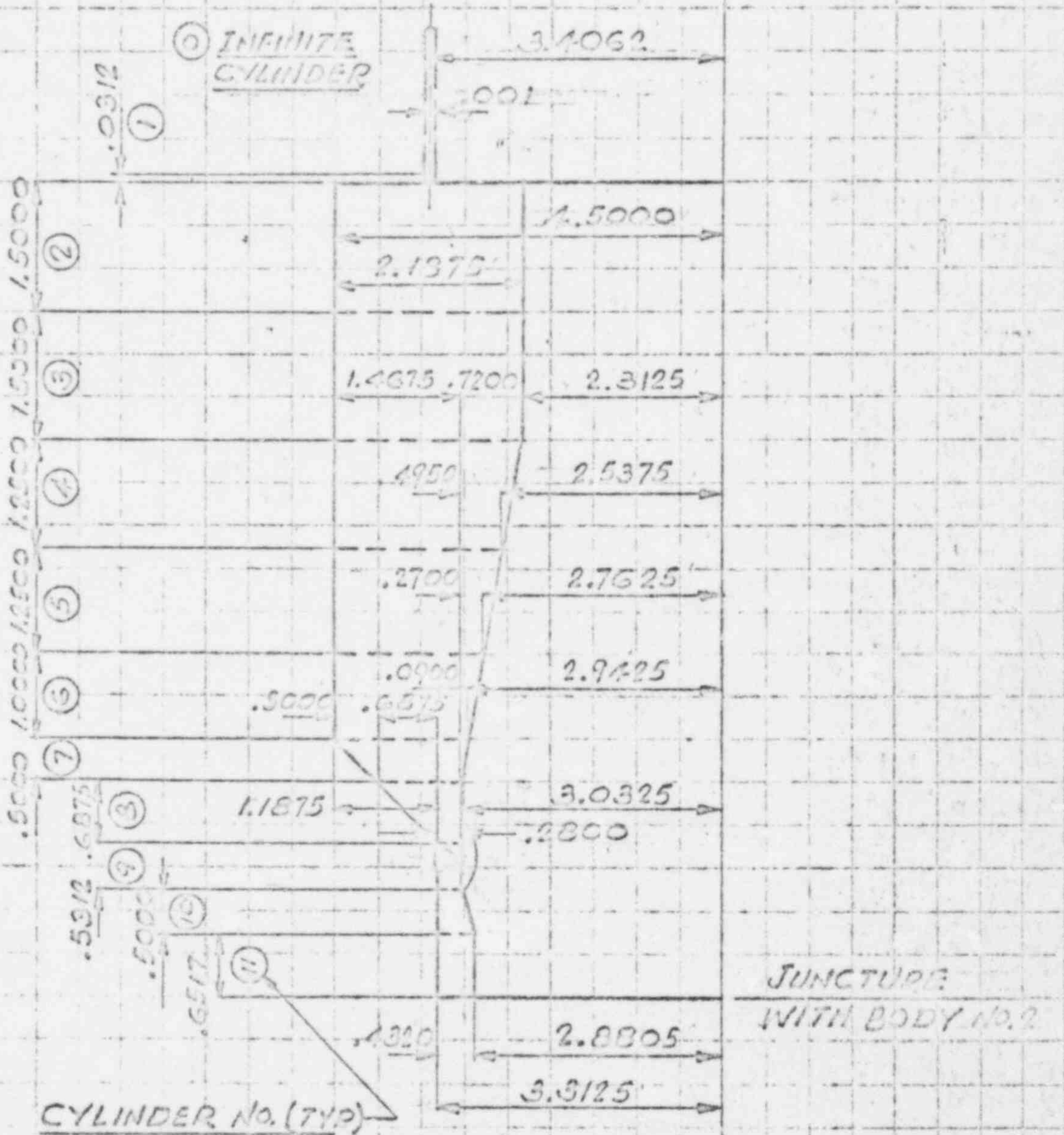
Analytical Model - continued

Because of a characteristic of the computer program, the nozzle is divided into two bodies as shown on the preceding page. The upper part of the nozzle and the point of failure are included in Body 1, which is subdivided into ten (10) short cylinders. The steam line, the reinforcing pad, the fillet welds and a short length of the nozzle are modeled as Body 2, which is subdivided into six (6) short cylinders. In order to seal internal pressure, a very thin "infinite" cylinder is located at each end of the analytical model.

To avoid complications, the upper part of Body 1 is modeled without steps. This simplication is justified by the practical observation that the flanges and the counterbore do not affect the failed Schedule 40 nozzle neck significantly.

The complex transition from nozzle to steam line is modeled very simply as a reasonably thick cylinder on the same axis as the nozzle. This simplification is justified by noting that the upper fillet weld is approximately a "long cylinder length" from the point of failure. In other words, neither the steam line nor the imaginary short cylinders interact significantly with the failed Schedule 40 nozzle neck.

DIMENSIONS AND ELEMENTS OF BODY NO. 1



NOTE: THESE DIMENSIONS ARE APPROXIMATE.

SCALE: $\frac{1}{2}$ X SIZE

DIMENSIONS AND ELEMENTS OF BODY NO. 2

NOTE:
THESE DIMENSIONS ARE APPROXIMATE.

SCALE: $\frac{1}{2}$ X SIZE

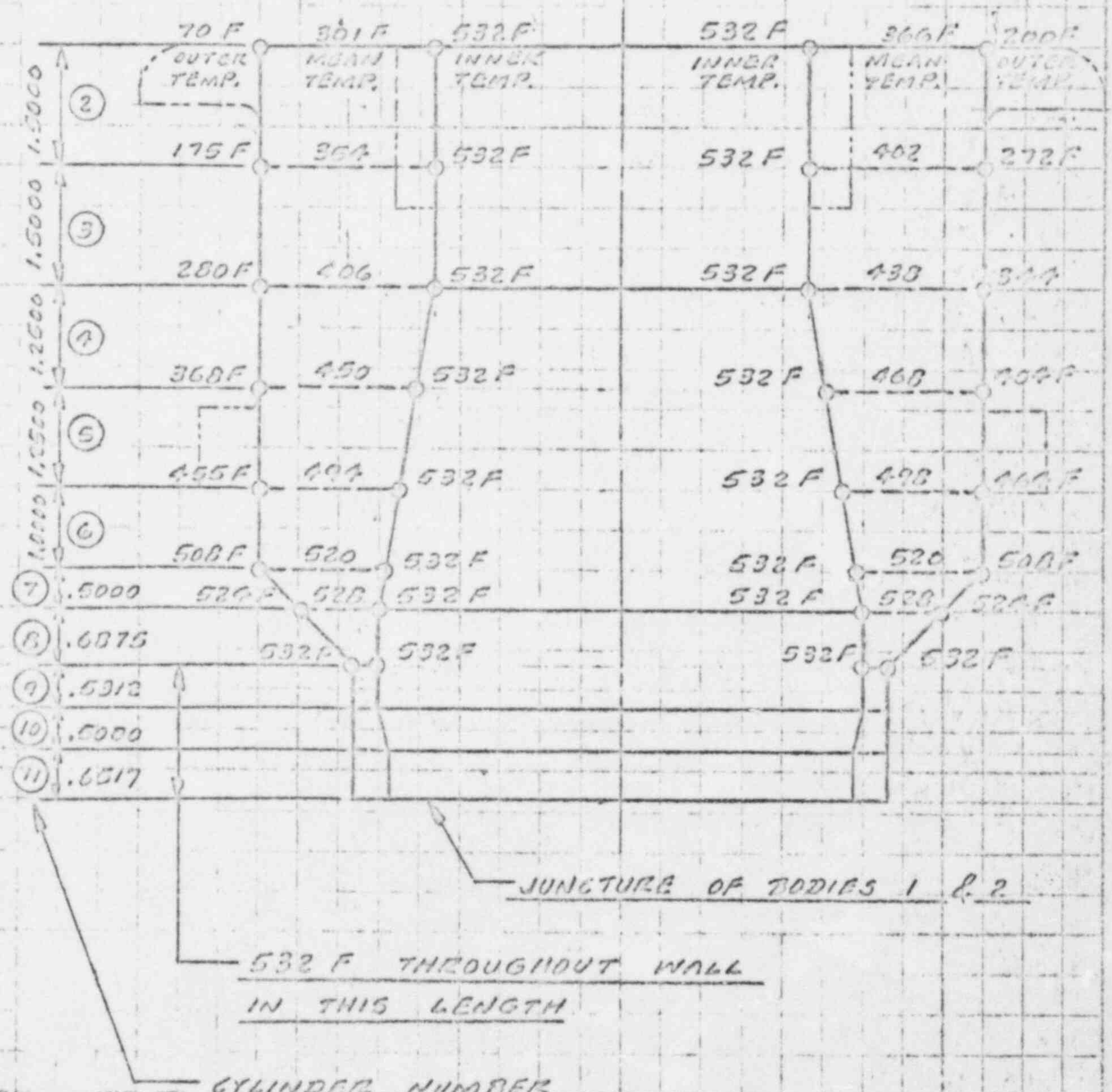
BY W. FOLEY DATE 5-22-70 SUBJECT ATTACHMENT NO. 4 SHEET NO. 17 OF

CHKD. BY RJD DATE 5-23-70 TO REPORT DC-67 JOB NO.

TEMPERATURE DISTRIBUTION OF BODY 1 FOR CONDITIONS 1 AND 2

CONDITION NO. 1
"TEMP 1"
RUNS 3 & 4

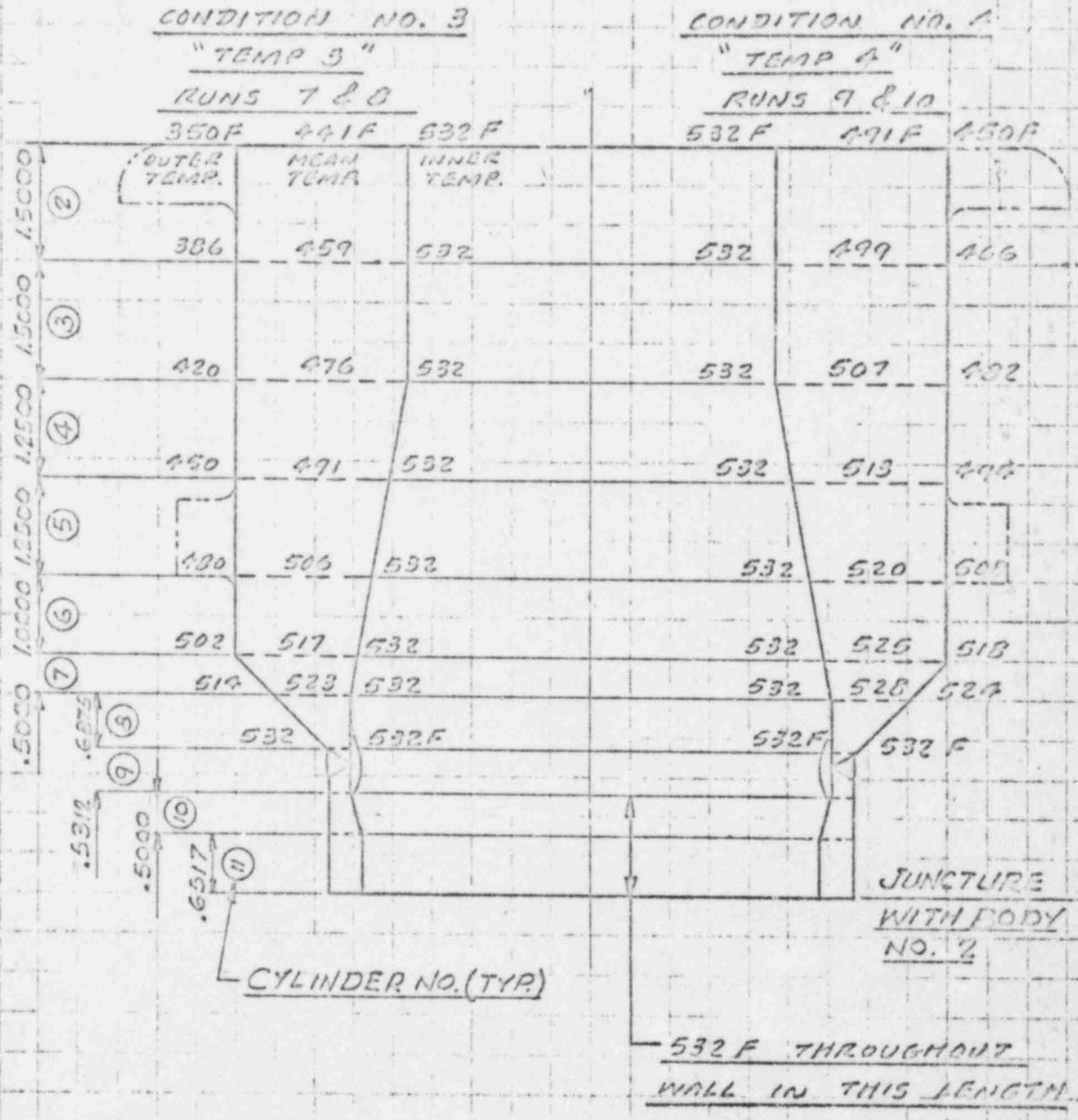
CONDITION NO. 2
"TEMP 2"
RUNS 5 & 6



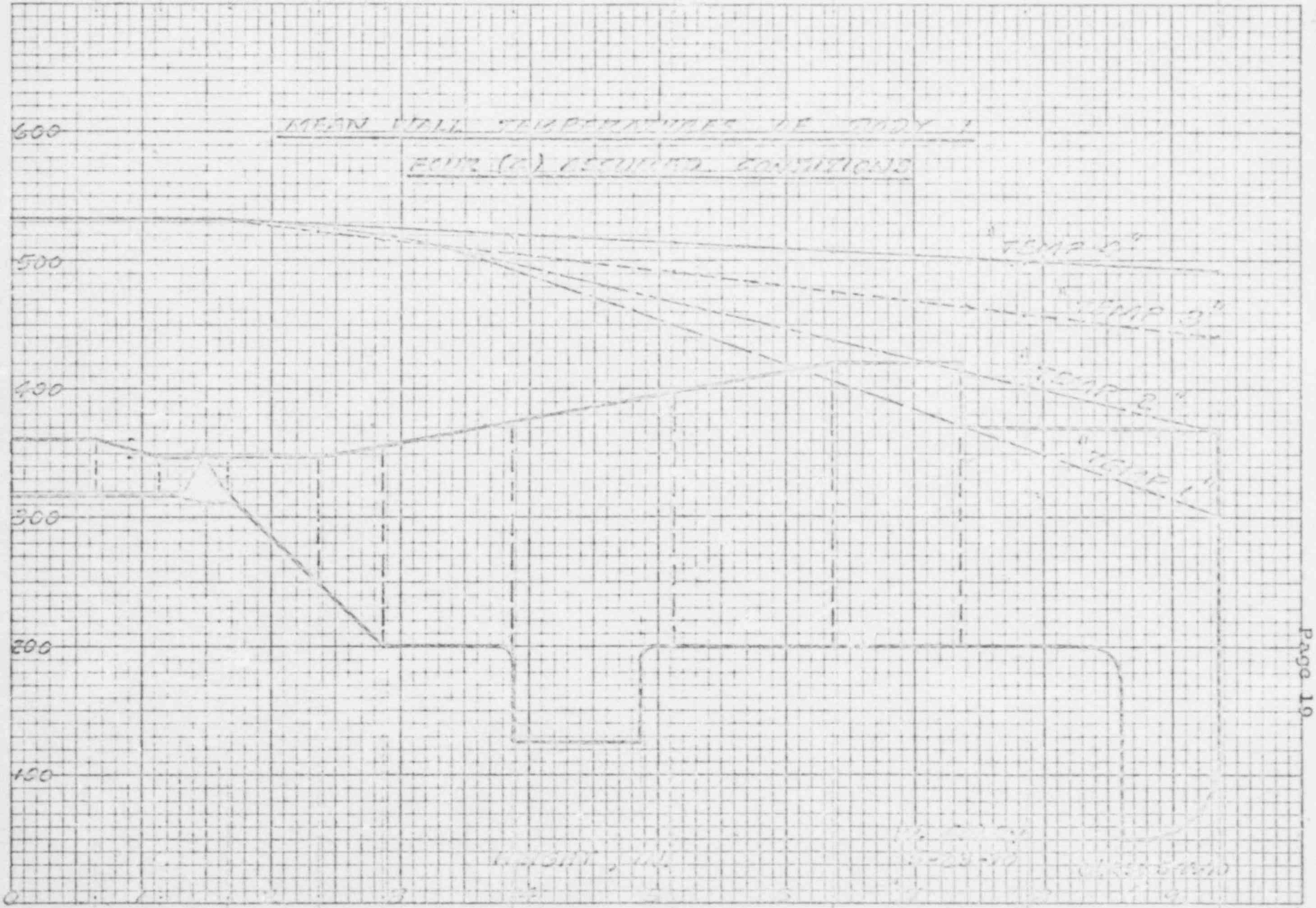
SCALE : 1/2 X SIZE

BY D.S. DATE 5-22-70 SUBJECT ATTACHMENT NO. 4 SHEET NO. 18 OF
CHKD. BY R.S. DATE 5-23-70 TO REPORT DC-67 JOB NO.

TEMPERATURE DISTRIBUTION OF BODY 1
FOR CONDITIONS 3 AND 4



SCALE : 1/2 X SIZE


600
500
400
300
200
100
0
"TEMP 3"
"TEMP 2"
"TEMP 1"

BY ... Coll... DATE 5-29-70 SUBJECT ATTACHMENT NO. 4 SHEET NO. 20 OF ......
CHKD. BY ...... DATE ...... TO REPORT DC-67 JOB NO. ......

STRESS CAUSED BY POSSIBLE POPPING

$$\sigma = \frac{M}{Z} = \frac{\overbrace{14{,}000^{\#}(30\,in)}^{\text{force and lever arm per G.W. Reinmuth - Telecon 5/22 RJL (to be defined)}}}{8.50} = \underline{49{,}413}\ psi.$$

(to be completed)
(later)

(hoter)