LOFT TECHNICAL REPORT LTR 1141-32
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LOFT STEAM GENERATOR THERMAL ANALYSIS CLASS I REVIEW

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IDAHO NATIONAL ENGINEERING LABORATORY

DEPARTMENT OF ENERGY

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RESEARCH, ENGINEERING AND CONSTRUCTION REPORT
ENGINEERING ANALYSIS DIVISION

THERMAL ANALYSIS

LOFT STEAM GENERATOR

THERMAL ANALYSIS CLASS I

REVIEW

MASTER

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[redacted]

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IDAHO NATIONAL ENGINEERING LABORATORY
LOFT TECHNICAL REPORT
LOFT PROGRAM

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AUTHOR	GWA NO.
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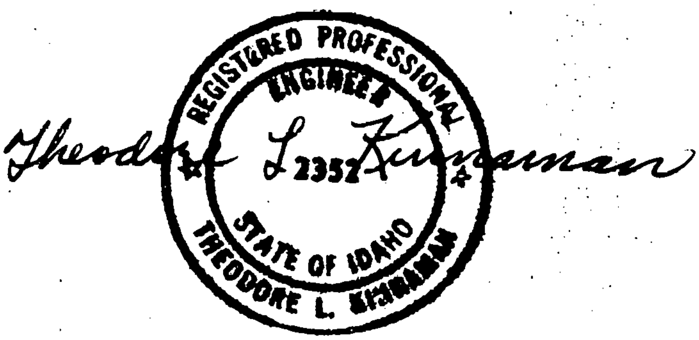
LOFT STEAM GENERATOR
THERMAL ANALYSIS
CLASS I REVIEW

I certify that the LOFT Steam Generator thermal analysis (References 1 through 5) has been reviewed and that this analysis meets the ASME Code, Section III thermal analysis requirements for Class I components for the thermal transients and conditions found in the LOFT Steam Generator Specification - ANC-60057 and the Preliminary Component Design Description for the Steam Generator - CDD 1.1.4.1B.



DISCUSSION

Thermal analyses were performed on the LOFT Steam Generator (LSG) by the Thermal Analysis Branch. The results of these analyses are documented by References 1 through 5. The first analysis[1] calculated the temperature response of selected steam generator components for normal operation transients, i.e., heatup, cooldown, plant loading, and plant unloading, and the two most severe upset transients, i.e., control rod drop and LOCE. The next two analyses[2],[3] considered the extremely severe case in which 70°F ECC water was assumed to contact the LSG inlet nozzle and tubesheet. The analysis documented by Reference 4 considered the transient case in which 70°F secondary feedwater was assumed to contact the LSG feedwater inlet nozzle which was at 540°F. The analysis documented by Reference 5 calculated the temperature response in the LSG thermal well for the following transients: (1) LOCE, (2) single control rod drop, and (3) heatup with 0 to 100% load change. All transients are as defined in References 6 and 7.

In accordance with the ASME Code requirements, all analyses of Class I components must be independently reviewed. Since the LOFT Steam Generator is a Class I component, the thermal analyses were reviewed as presented in Appendix A. Appendix B contains the Thermal Analysis Branch comments to this review. It is the opinion of the Thermal Analysis Branch that these comments satisfy all of the reviewer's questions and that the analyses should stand as is, without additional considerations, in meeting the ASME Code requirements, CDD 1.1.4.1B[6] and ANC Specification 60057[7].

REFERENCES

1. E. C. Lemmon, LOFT Steam Generator Thermal Analysis, LTR 1141-26 (July 27, 1976).

2. B. J. Tolan, LOFT Steam Generator Thermal Analysis, LTR 1141-26 Supplement 1 (January 3, 1977).

3. T. L. Kinnaman, LOFT Steam Generator Inlet Nozzle Thermal Analysis For Cold ECC, LTR 1141-26 Supplement 3 (May 4, 1977).

4. B. J. Tolan, LOFT Steam Generator Feedwater Nozzle Analysis, LTR 1141-26 Supplement 2 (February 10, 1977).

5. G. T. Rainey, Transient Thermal Analysis of LOFT Steam Generator Thermal Well, LTR 1141-15 (February 11, 1975).

6. Aerojet Nuclear Company Specification ANC-60057 Revision A, LOFT Steam Generator (July 27, 1973).

7. LOFT Integral Test System - Preliminary Component Design Description for the Steam Generator, Report No. CDD 1.1.4.1B, EG&G Idaho, Inc., INEL, Idaho Falls, Idaho (December 1970).

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LTR No. 1141-32 Appendix A

REACTOR BEHAVIOR DIVISION

TECHNICAL REPORT

LOFT STEAM GENERATOR THERMAL ANALYSIS INCLUDING THERMAL WELL CLASS 1 REVIEW

By

D. K. Patel

D.K. Patel
D. K. Patel, Author

Approved By:

O J Demuth
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APPENDIX A

REVIEW OF LOFT STEAM GENERATOR THERMAL ANALYSIS

SUMMARY OF THE REVIEW

The thermal analyses contained in the LOFT Steam Generator (LSG) reports, including the thermal well report (References 1,2,3,4,5) were found to conservatively meet the requirements of the LOFT Technical Specifications[6][8] as well as the LOFT Integral Test System - Preliminary Component Design Description for the Steam Generator[7] with the following exceptions and/or questions:

(1) Details of any thermal analysis of the steam generator at elevations above the feed-water inlet nozzle are not available, nor is reference made to such considerations.

(2) On page 35 of Reference 1, the boundary conditions of "Rod Withdrawal Accident and Scram from 100% Power" are shown. In this figure for the primary side, Δt=0.833 min is shown, but according to LOFT Specification[6] Δt should be close to 30 seconds to be conservative.

(3) Insufficient details are given to quantitatively check the numerical values for some of the heat transfer coefficients used. Qualitatively, the magnitudes appeared consistent with the boundary conditions intended.

(4) No input data to COUPLE[9] is shown in LOFT Steam Generator Report[1]; consequently, the input data could not be checked in detail. However, no reason arose for questioning the validity of code input.

(5) The specifications (see References 6 and 7) did not show sufficient information to define the fluid-temperature boundary conditions for the secondary side of the LSG for upset transient conditions.

(6) In Section II.2.4 three minor apparent discrepancies relative to materials used for the analyses are mentioned.

(7) Reasons for omitting thermal analyses of the "Loss of Secondary Coolant from 100% Design Basis Earthquake" condition (see Reference 6, page 8) were not given.

There were some typographical errors noted, and Figures E1 and E2 were missing from Reference 1, but these items were judged not to affect the review.

It is recommended that these exceptions and questions be reviewed by the members of the Thermal Analysis Section, and that their judgment be followed relative to any subsequent action required.

TABLE OF CONTENTS

I. INTRODUCTION

A Class 1 review of the thermal analysis contained in the LOFT Steam Generator Report by E. C. Lemmon[1], LTR 1141-26 Supplement 1[2], LTR 1141-26 Supplement 2[3] and LTR 1141-26 Supplement 3[4], as well as Transient Thermal Analysis of LOFT Steam Generator Thermal Well by G. T. Rainey (LTR 1141-15)[5] were made to confirm compliance of the analysis with the LOFT Technical Specifications ANC 60057[6], with the LOFT Integral Test System - Preliminary Component Design Description for the Steam Generator[7], and with Appendix C of ANC Specification 60139[8]. Included in this review was an examination of the thermal transients and conditions contained in the LOFT Steam Generator Report[1] to insure that the authors conservatively analyzed conditions and transientsto which the LOFT Steam Generator (including thermal well) might be exposed while in service at the LOFT reactor facility. Also, a review of the thermal code given in COUPLE[9] was made to check for its applicability to these analyses.

II. DISCUSSION

1. REVIEW OF COUPLE

A review of the technical report "COUPLE - A Two-Dimensional Finite Element Steady-State and Transient Heat Conduction Code"[1] was made to confirm the procedure of the calculations used in LOFT Steam Generator (LSG) Thermal Analysis. A review was made of the finite element method utilized, as well as the method of weighted residuals. It was noted that the code computes the steady-state and/or transient temperature distributions of two-dimensional bodies subjected to convection, radiation, prescribed heat flux, and temperature boundary conditions. COUPLE also handles homogeneous anisotropic materials with temperature-dependent properties for either axisymmetric or plane geometries.

Overall, the computer code and calculation procedure shown in this technical report[9] were judged to be applicable for the analyses reviewed.

2. BOUNDARY CONDITIONS

2.1 Fluid Temperature Transients

The normal transients as well as the upset transients are shown for the primary side and secondary side of the LSG. The boundary conditions shown in the LSG reports[1,2,3,4,5] were found to conservatively meet the requirements of the LOFT Technical Specifications[6][8] as well as the LOFT Integral Test System Report of the Steam Generator[7] with the following exceptions and/or questions:

(1) The upset transients for the secondary side of the LSG (Section 3.1 of Reference 1) could not be found in either Reference 6 or 7. The values used in the analyses appeared reasonable, but could not be checked.

(2) On page 38 in Table I of Reference 1 complete summary of Section 3.1 (Reference 1) is given. A comparison of Section 3.1 and Table I shows that for the primary and secondary sides the following data are not in match:

(a) Plant Heatup and Cooldown. $\frac{\Delta T}{\Delta t} = 2.77 \times 10^{-4} \frac{°F}{sec}$ is given in Table I; the value should be 2.77×10^{-2}.

(b) Step Load Rejection - Secondary Side. $\frac{\Delta T}{\Delta t} = -1.77 \frac{°F}{sec}$ is given in Table I; the value should be 0.425.

(c) Reactor Trip - Secondary Side. $\Delta t = .16$ min is given in Table I; Δt should be 0.5 min (Ref. 1, Sec. 3.1). $\frac{\Delta T}{\Delta t} = 3.33 \frac{°F}{sec}$ is given in Table I; the value should be $1.01 \frac{°F}{sec}$.

(d) Loss of Flow - Secondary Side. $\Delta t = 0.16$ min is given in Table I; Δt should be 1/3 min (Sec. 3.1). $\frac{\Delta T}{\Delta t} = 3.33 \frac{°F}{sec}$ is given in Table I; the value should be $1.6 \frac{°F}{sec}$.

(e) Loss of Site Power - Secondary Side. $\Delta t = 0.16$ min is given in Table I; Δt should be 25 sec (Section 3.1). $\frac{\Delta T}{\Delta t} = 3.33 \frac{°F}{sec}$ given in Table I; the value should be $1.28 \frac{°F}{sec}$.

It is assumed that these discrepancies are of a typographical category, and that the correct values were input into the calculations. However, as mentioned in Section 1.1, paragraph (1) above, this input could not be checked.

(3) The details of the input data relative to fluid temperature vs. time (boundary conditions to the computer analysis) are not shown in Reference 1. Thus, it was not possible to check the actual computer input.

(4) On page 35 of Reference 1, the boundary conditions of rod withdrawal accident and scram from 100% power are shown. In this figure for the primary side, $\Delta t = 0.833$ min is shown, but according to LOFT Specifications[6] a better conservative value for Δt might be close to 30 seconds.

2.2 Determination of Surface Heat Transfer Coefficients

1. On page C-15 of Reference 1, a complete list of the heat transfer coefficients is given in the table for application to each of the transients. On pages C-16, C-17 and C-18 an explanation is shown for the derivation of h's. Using the available information, heat transfer coefficients (a), (b), (c), (d), (g), (i) and (j) were reviewed, and found to be appropriate. But due to insufficient information, heat transfer coefficients (e), (f) and (h) could not be checked. Their numerical magnitudes, however, appeared consistent with their application.

2. On page 8 of Reference 5, the heat transfer coefficients are given, but the derivation of these coefficients are not available in the report; therefore, the values were not checked quantitatively. Again, no apparent inconsistencies were noted.

2.3 Selection of Models for Analysis

Thermal analyses were carried out for the following components of the steam generator[1,2,3,4,5]:

(1) Primary Shell

(2) Primary Shell - Tube Sheet Intersection

(3) Primary Shell Nozzle

(4) Handhole

(5) Manhole or Manway

(6) Skirt Junction

(7) Secondary Side Feed-water Nozzle

(8) Primary Nozzle Orifice Plate Assembly

2.3.1 Noding. Each model was divided into small elements, either rectangular or triangular, according to the shape of the model and location of elements in the model. Also, it was noted that in a region where the wall thickness is small and the temperature gradient is high, a fine grid was adopted in order to maintain the accuracy. Also, in the models where temperature gradients are very small, a coarse grid was adopted. This procedure is reasonable to obtain accurate engineering results with computer time constrained.

Overall, the method adopted to divide the model into elements, and the numbering system adopted for elements as well as node points, was judged to be very satisfactory.

2.4 Checks of Materials and Properties

In this review, material properties were checked at the node points for all models. Materials and properties checked satisfactorily except for the following:

(1) On page A-12 of Reference 1, the material #2 appears wrong for element #42; it should be material #9.

(2) On page A-6 of Reference 1, in the primary shell model near the skirt region, materials #1 and #2 are used, but on page A-73 of Reference 1 in the skirt junction model only material #1 is used. No explanation was found available for this apparent discrepancy.

(3) On page B-4 of Reference 1, it is mentioned that material #6 (Inconel) is not used. In the same report, material #6 was called out in several locations (e.g., page A-12, element #'s 90 and 91).

In the axisymmetric bodies, to simplify the complication introduced by the three-dimensional geometry, the equivalent material properties are calculated for "smeared" bolts as well as for "smeared" bolt holes (Reference 1, pages B-7, B-10, B-11). Similarly, the equivalent material properties of the tube plates with cladding (Inconel) is shown on page B-7 in Reference 1. The approach of conserving mass, heat capacity, and overall conductance, used in the "smearing" technique, is appropriate.

3. CONFORMANCE WITH TRANSIENTS OF SPECIFICATIONS

References (1)-(5) were reviewed relative to LOFT Specifications (References (6), (7) and (8)) for normal and upset transients and number of occurrences in the steam generator life. It was judged that the transient conditions in the specifications are covered by the analysis conducted with the following possible exception:

The emergency condition "Loss of Secondary Coolant from 100% Design Basis Earthquake" was not thermally analyzed. Reference 6, page 8, indicates that this condition is assumed to be a five-cycle occurrence in the LSG life. No discussion was presented as to the reason for not considering this condition.

4. RESOLUTION OF INCORRECT INITIAL ANALYSES

4.1 Primary Nozzle Model

According to the discussion given on page E-1 (Reference 1), the thermal analysis of the primary nozzle was repeated, because the previous analysis was incorrect. The latter corrected results show that the thermal gradients are less than or equal to those in the incorrect result. Thus, the nozzle designed, based on the original calculation, is safe for applicability.

4.2 Primary Shell Model

The calculation of the thermal analysis of the primary shell model was also repeated, because the previous analysis was incorrect. Now, according to Figures E-21 and E-22, greater temperature gradients were observed in the new corrected calculation. Thus, it is appropriate to check the stress analysis of the primary shell model using the new thermal results, as was recommended in Reference 1.

III. REFERENCES

1. E. C. Lemmon, "LOFT Steam Generator Thermal Analysis", LOFT Technical Report LTR 1141-26, EG&G Idaho, Inc., INEL, Idaho Falls, Idaho (July 1976).

2. B. J. Tolan, LTR 1141-26, Supplement 1, EG&G Idaho, Inc., INEL, Idaho Falls, Idaho (Januarn 1977).

3. B. J. Tolan, LTR 1141-26, Supplement 2, EG&G Idaho, Inc., Idaho Falls, Idaho (February 1977).

4. T. L. Kinnaman, LTR 1141-26, Supplement 3, EG&G Idaho, Inc., Idaho Falls, Idaho (May 1977).

5. G. T. Rainey, "Transient Thermal Analysis of LOFT Steam Generator Thermal Well", LTR 1141-15, Aerojet Nuclear Company, Idaho Falls, Idaho (February 1975).

6. LOFT Technical Specifications, ANC-60057 for LOFT Steam Generator, Aerojet Nuclear Company, Idaho Falls, Idaho (July 1973).

7. LOFT Integral Test System - Preliminary Component Design Description for the Steam Generator, Report No. CDD 1.1.4.1B, EG&G Idaho, Inc., INEL, Idaho Falls, Idaho (December 1970).

8. Transient Grouping for Thermal Analysis (Appendix C of ANC Specification 60139, LOFT Class I Nuclear Piping System).

9. E. C. Lemmon, "COUPLE - A Two-Dimensional Finite Element Steady-State and Transient Heat Conduction Code for Use on an IBM 360/75 Computer", TR-471, TA-15, Aerojet Nuclear Company (February 1974).

APPENDIX B

RESOLUTION OF REVIEWERS COMMENTS TO THE LOFT STEAM GENERATOR THERMAL ANALYSES

RESOLUTION OF REVIEWERS' COMMENTS

Resolution of the reviewers comments to the LOFT Steam Generator thermal analyses will be handled on a comment by comment basis. The reviewers comment will be given first followed by the Thermal Analysis Branch resolution to that comment. Reference numbers used in the review comments and the resolution of the comments apply to the list of references in this LTR.

(1) Comment:

The upset transients for the secondary side of the LSG (Section 3.1 of Reference 1) could not be found in either Reference 6 or 7. The values used in the analyses appeared reasonable, but could not be checked.

Resolution:

The upset transients for the secondary side of LSG were obtained from the steam pressure versus time plots from References 6 and 7 by obtaining the saturation temperatures corresponding to the steam pressure at each time increment.

(2) Comment:

On page 38 in Table I of Reference 1 complete summary of Section 3.1 (Reference 1) is given. A comparison of Section 3.1 and Table I shows that for the primary and secondary sides the following data are not in match:

(a) Plant Heatup and Cooldown. $\frac{\Delta T}{\Delta t} = 2.77 \times 10^{-4} \frac{°F}{sec}$ is given in Table I; the value should be $2.77 \times 10^{-2} \frac{°F}{sec}$.

(b) Step Load Rejection - Secondary Side. $\frac{\Delta T}{\Delta t} = -1.77 \frac{°F}{sec}$ is given in Table I; the value should be $0.425 \frac{°F}{sec}$.

(c) Reactor Trip - Secondary Side. Δt = .16 min is given in Table I; Δt should be 0.5 min (Ref. 1, Sec. 3.1). $\frac{\Delta T}{\Delta t} = 3.33 \frac{°F}{sec}$ is given in Table I; the value should be 1.01.

(d) Loss of Flow - Secondary Side. Δt = 0.16 min is given in Table I; Δt should be 1/3 min (Sec. 3.1). $\frac{\Delta T}{\Delta t} = 3.33 \frac{°F}{sec}$ in Table I; the value should be 1.6 $\frac{°F}{sec}$.

(e) Loss of Site Power - Secondary Side. Δt = 0.16 min is given in Table I; Δt should be 25 sec (Section 3.1.). $\frac{\Delta T}{\Delta t} = 3.33 \frac{°F}{sec}$ given in Table I; the value should be 1.28 $\frac{°F}{sec}$.

It is assumed that these discrepancies are of a typographical category, and that the correct values were input into the calculations.

Resolution:

Thermal Analysis agrees that the above values for Δt and $\Delta T/\Delta t$ given in Table I of Reference 1 are in error. Errors in typing or calculating the $\Delta T/\Delta t$ from ΔT and Δt are the most likely causes. The correct transient information was input in the calculations, however. In addition, it should be mentioned that due to the transients analyzed (plant heatup, cool-down, loading, unloading, LOCE, and rod drop), the errors pointed out in items 2(b) through 2(e) above are of no consequence as far as the LSG thermal analyses is concerned.

(3) Comment:

The details of the input data relative to fluid temperature vs time (boundary conditions to the computer analysis) are not shown in Reference 1. Thus, it was not possible to check the actual computer input.

Resolution:

Inclusion of all of the input boundary conditions into the report (Reference 1) would result in a significantly larger report making it more difficult to read and interpret. Thermal Analysis people checked this input data before the results were transmitted for stress analysis, however.

(4) Comment:

On page 35 of Reference 1, the boundary conditions of rod withdrawal accident and scram from 100% power are shown. In this figure for the primary side, Δt = 0.833 min is shown, but according to LOFT Specifications[6] a better conservative value for Δt might be close to 30 seconds

Resolution:

The value of Δt from Figure 6 of the steam generator specification[6] depends largely on how carefully and accurately the steam generator inlet temperature vs time curve is interpreted. Δt interpretations of this curve can easily vary from 0.5 min. to 0.833 min. Using a more conservative Δt value of 30 seconds results in a ΔT/Δt value less than that for the LOCE or rod drop transient. Therefore, the Δt value of 0.833 min. has no affect on the analysis.

(5) Comment:

On page C-15 of Reference 1, a complete list of the heat transfer coefficients is given in the table for application to each of the transients. On pages C-16, C-17 and C-18 an explanation is shown for the derivation of h's. Using the available information, heat transfer coefficients (a), (b), (c), (d), (g), (i) and (j) were reviewed, and found to be appropriate. But due to insufficient information, heat transfer coefficients (e), (f) and (h) could not be checked. Their numerical magnitudes, however, appeared consistent with their application.

Resolution:

Thermal Analysis discussed this comment with the author of Reference 1. The author believes the heat transfer coefficients (e), (f), and (h) to be appropriate and conservative for the applications.

(6) Comment:

On page 8 of Reference 5, the heat transfer coefficients are given, but the derivation of these coefficients are not available in the report; therefore, the values were not checked quantitatively. Again, no apparent inconsistencies were noted.

Resolution

The heat transfer coefficients were calculated from the Dittus-Boelter correlation as well as other appropriate correlations. The coefficients used are believed to be reasonable and conservative for the applications.

(7) Comment:

On page A-12 of Reference 1, the material #2 appears wrong for element #42; it should be material #9.

Resolution

The Thermal Analysis Branch concurs. This error will not appreciably affect the computed thermal gradients in this location on the primary shell model. Material #9 makes up the bolt holes on the manway cover and has been assigned smeared thermal and physical properties. The thermal conductivity of the smeared hole is 2/3 the thermal conductivity of Material #2. With Material #9 surrounded by Material #2, the effect of replacing one element of Material #9 with one element of Material #2 will be slight.

(8) Comment:

On page A-6 of Reference 1, in the primary shell model near the skirt region, Materials #1 and #2 are used, but on page A-73 of Reference 1 in the skirt junction model only Material #1 is used. No explanation was found available for this apparent discrepancy.

Resolution

An apparent error was made in assigning the material numbers to the respective elements. Since materials 1 and 2 have identical thermal properties, no affect on the computed thermal gradients will be seen.

(9) Comment:

On page B-4 of Reference 1, it is mentioned that Material #6 (Inconel) is not used. In the same report, Material #6 was called out in several locations (e.g., page A-12, element #'s 90 and 91).

Resolution:

This was an oversight on the part of the analyst. Such a small portion of the primary shell model was assigned Material #6 (2 elements) that the analyst overlooked it when assigning material numbers to the figure on page B-4 of Reference 1. This oversite had no effect on the thermal analysis results.

(10) Comment:

The emergency condition "Loss of Secondary Coolant form 100% Design Basis Earthquake" was not thermally analyzed. Reference 6, page 8, indicates that this condition is assumed to be a five-cycle occurrence in the LSG life. No discussion was presented as to the reason for not considering this condition.

Resolution

The ASME Code does not require thermal analysis of emergency conditions.

(11) Comment:

Details of any thermal analysis of the steam generator at elevations above the feed-water inlet nozzle are not available, nor is reference made to such considerations.

Resolution

Computed temperature responses of LSG components above the feedwater inlet nozzle are expected to be less severe than those below the nozzle and hence were not analyzed.