ATTACHMENT 4

WCAP-7907-S1-NP, Revision 1
"LOFTRAN Code Description, Supplement 1
LOFTRAN Thick Metal Mass Heat Transfer Models"
(non-proprietary)

WCAP-7907-S1-NP, Revision 1

LOFTRAN
CODE DESCRIPTION

Supplement 1 - LOFTRAN Thick Metal Mass Heat Transfer Models

January 2001

Contents

1. Introduction

Heat transfer to and from metal in the reactor coolant system (RCS) is ignored in most non-LOCA analyses performed with LOFTRAN. This is conservative in the sense that it minimizes the primary system heat capacity and thus accentuates reactor coolant system temperature changes. One situation where neglecting heat transfer between the RCS metal and coolant would not be conservative is in the computation of mass and energy release following a steam line break. LOFTRAN as previous licensed in WCAP-7907-P-A (Reference 1) includes a simplified thick metal mass heat transfer model for use in steam line break transients to conservatively over-predict the heat transfer from the thick metal to the reactor coolant fluid.

In transients with a large and relatively slow increase of RCS temperature, such as a loss of normal feedwater with minimum auxiliary feedwater flow, there would be a substantial amount of heat absorbed in the RCS thick metal. While it is conservative to ignore this effect in these types of transients, this conservatism is considered unnecessary. However, for modeling and crediting the heat absorption characteristics of RCS thick metal masses, the simplified thick metal mass heat transfer model in LOFTRAN is considered to be inappropriate because it would overestimate the heat transfer to the thick metal.

Therefore, an optional enhanced model which is more detailed and accurate has been developed and incorporated into LOFTRAN. This report will summarize the original simplified thick metal model and the new enhanced thick metal model. Comparison calculations between the enhanced model and those of other methods are provided for validation.

2. Simple LOFTRAN Thick Metal Model

LOFTRAN includes a simplified thick metal mass heat transfer model. This model was implemented for the steam line break methodology developed in Reference 2 (see Section 3.1.2 of WCAP-8822). The methodology for steam line break mass and energy releases was approved by the U.S. NRC in 1986 (see Reference 3). This simplified thick metal mass model is specifically used for steam line break mass and energy release calculations to conservatively maximize the heat input to the primary coolant during the plant cooldown. The simplified thick metal mass heat transfer model uses a lumped system model. The metal in the RCS is divided into the [ ] regions identified in Table 2-1. Figure 2-1 illustrates the model. +a, c
The code input variables for the model consists of only two input arrays which are described in Table 2-2.

Table 2-1	
Regions Number (k)	Description
[	] +a, c

Table 2-2 Code Input for Simplified Thick Metal Model		
Variable	Dimension	Description
[		] +a, c

The heat capacity of RCS components are found by multiplying the metal mass of the components by the specific heats of the metal used. The heat capacity of a region is found by summing the heat capacities of the metal components within the region.

The heat transfer coefficient from the metal to the RCS fluid is [ ] and is +a, c defined by the input UATM array. The input heat transfer coefficient accounts for the film heat transfer coefficient and the metal conductivity. The initial metal temperatures are assumed to be equal to the fluid temperature in adjacent regions.

The energy transferred from the metal to the reactor coolant fluid during a time step is calculated using:

[ ] +a, c

where

$E(k)$	=	energy transferred from metal region "k" to RCS fluid region "k" during the time step
$T_{M(k)}(t)$	=	Temperature of metal region "k" at time=t, °F
$T_{RCS}(k)$	=	Fluid temperature in RCS region "k", °F
Δt	=	time step size, sec.

The temperature of the metal at the next time step will be:

[ ] +a, c

[ ]$^{+a, c}$

Figure 2-1 LOFTRAN Simple Thick Metal Mass Heat Transfer Model

3. Enhanced LOFTRAN Thick Metal Model

In transients with a large and relatively slow increase of RCS temperature, such as a loss of normal feedwater with minimum auxiliary feedwater flow, there may be a substantial amount of heat absorbed in the RCS thick metal. While trying to maximize the heatup of the RCS, it is conservative to ignore the heat absorbed in the RCS thick metal. This conservatism is considered unnecessary. The simple thick metal mass heat transfer model as described in Section 2 cannot provide a reasonable estimate of the actual heat transfer between the reactor coolant fluid and metal. Therefore, an enhanced thick metal mass heat transfer model is needed to quantify the energy absorbed in the RCS metal during heat up type transients. A more detailed and accurate model as described in this section was developed and incorporated into LOFTRAN.

The methodology used in the model is summarized in the following subsections. A description of the metal noding scheme used and the code input is provided in Section 3.1. Subsection 3.3 summarizes the initialization calculations performed. The enhanced metal heat transfer model solves for the transient metal lump temperatures using a[

+a,c

] The transient solution is summarized more in Section 3.4.

3.1 Metal Noding and Code Input

Like the original simple thick metal model described in Section 2, the enhanced thick metal model uses several RCS regions. The regions are identified in Table 3.1-1 and are the same as those of the simple model.

Table 3.1-1 RCS Regions

Region Number (k)	Description

[ ] +a,c

The enhanced thick metal mass heat transfer model incorporates the following new features which improve the accuracy of the heat transfer in the thick metal mass heat transfer model. The capability of the metal noding scheme for a given region is illustrated in Figure 3.1-1.

- Each region can contain up to [ ] +a, c A surface area of zero causes that metal section and any higher numbered metal sections to be ignored.

- Within each metal section, up to [ ] +a, c The thickness and material for each lump is specified by input values. A thickness of 0.0 for any metal lump results in that lump and any higher numbered lumps in the metal section to be ignored (i.e., no stored energy or heat transfer).

- A metal section can have three possible geometric configurations:
  a) flat slab
  b) cylinder with the inner surface of the cylinder wetted
  c) cylinder with the outer surface of the cylinder wetted

  Figures 3.1-2a, 2b and 2c illustrate the possible metal section geometries.

- The film coefficient between the RCS fluid and the thick metal varies as conditions change during the transient. The film heat transfer coefficient is calculated by the code using [ ] +a, c

Permissible code input variables for the enhanced thick metal mass heat transfer model are summarized in Table 3.1-2. In Table 3.1-2 and the following sections for description of the enhanced thick metal model, the following indices scheme is used for variables and arrays:

variable xyz(i, j, k, lp) where [ ] +a, c

Table 3.1-2 Code Input

Variable	Dimension	Description

+a, c

Table 3.1-2 Code Input (continued)

Variable	Dimension	Description

+a, c

+a, c

Figure 3.1-1 Metal Node Scheme for Region "k"

+a, c

Figure 3.1-2a Flat Slab Metal Section
(used if the absolute value of DSURFTM(j,k) $\geq 1x10^{5}$)

+a, c

Figure 3.1-2b Cylindrical Metal Section With Inner Surface Wetted

+a, c

Figure 3.1-2c Cylindrical Metal Section with Outer Surface Wetted

3.2 Metal Properties

The model contains the option to use several sets of standard material properties or allow input values to be used. Tables 3.2-1 through 3.2-3 summarize the options available for the metal specific heat, conductivity or density. The properties for each metal slab are interpolated from Tables 3.2-1through 3.2-3 at the appropriate metal temperature.

Table 3.2-1 Metal Specific Heat									
Carbon Steel MATERTM(i,j,k)=1		Stainless Steel MATERTM(i,j,k)=2		VVER-1000 Carbon Steel MATERTM(i,j,k)=3		VVER-1000 Stainless Steel MATERTM(i,j,k)=4		Code User Input MATERTM(i,j,k)=5	
Temperature, °F	C_p BTU/lbm-°F	Temperature, °F	C_p BTU/lbm-°F	Temperature °F	C_p BTU/lbm-°F	Temperature, °F	C_p BTU/lbm-°F	Temperature °F	C_p BTU/lbm-°F
80.6	.106	70	.108	212	0.1120	212	0.0929	Specific heat is set to input value of USERPROP(1) at all temperatures	
260.6	.119	250	.122	392	0.1321	392	0.1120		
620.6	.139	550	.129	572	0.1431	572	0.1280		
980.6	.166	700	.132	752	0.1500	752	0.1309		

Table 3.2-2 Metal Thermal Conductivity									
Carbon Steel MATERTM(i,j,k)=1		Stainless Steel MATERTM(i,j,k)=2		VVER-1000 Carbon Steel MATERTM(i,j,k)=3		VVER-1000 Stainless Steel MATERTM(i,j,k)=4		Code User Input MATERTM(i,j,k)=5	
Temperature, °F	k BTU/hr-°F-ft	Temperature, °F	k BTU/hr-°F-ft	Temperature °F	k BTU/hr-°F-ft	Temperature, °F	k BTU/hr-°F-ft	Temperature °F	k BTU/hr-°F-ft
80.6	36.9	70	8.84	212	22.31	212	9.44	Thermal conductivity is set to input value of USERPROP(2) at all temperatures	
260.6	33.9	250	9.58	392	27.78	392	10.16		
620.6	28.1	550	10.82	572	30.24	572	10.89		
980.6	21.6	700	11.44	752	31.32	752	12.34		

Table 3.2-3 Metal Density				
Carbon Steel MATERTM(i,j,k)=1	Stainless Steel MATERTM(i,j,k)=2	VVER-1000 Carbon Steel MATERTM(i,j,k)=3	VVER-1000 Stainless Steel MATERTM(i,j,k)=4	Code User Input MATERTM(i,j,k)=5
Density, lbm/ft³	Density, lbm/ft³	Density, lbm/ft³	Density, lbm/ft³	Density, lbm/ft³
490.	490.	490.	493.	Density is set to input value of USERPROP(3)

3.3 Initialization Calculations

3.3.1 Initial Metal Temperatures

The initial metal temperature ($T_{Metal}(i,j,k,lp)$) for each metal lump is set to the appropriate adjacent RCS region fluid temperature.

3.3.2 Metal Volumes, Masses & Initial UA

The model performs calculations for three possible geometric configurations for each metal region.

- Case a - Flat Metal Slab
- Case b - Cylindrical Metal Section with the Inner Surface Wetted
- Case c - Cylindrical Metal Section with the Outer Surface Wetted

The calculations for Cases a, b & c are provided below. The model is not limited to simulating only flat slabs and hollow cylinders. The equations used for Cases a, b and c can also be adapted for simulating hollow spheres and irregularly shaped pieces. A discussion for following configurations is also provided.

- Case d - Spherical Metal Section with Inner Surface Wetted
- Case e - Irregularly-Shaped Metal Sections

Case a Flat Metal Slab

Referring to Figure 3.3-1a, the volume of the metal lumps in a slab are calculated using the following

[ ] +a, c

where V(i,j,k) is the plant total volume

[ ] +a, c

The heat capacitance for the metal lump is then calculated using

[ ] +a, c

Next the initial heat transfer coefficients (UA) are calculated. UA(i,j,k) is defined as being from Metal Lump i to Metal Lump i-1. The UA is defined as being between the midpoints of Lumps i & i-1.

+a, c

Case b   Cylindrical Metal Section with the Inner Surface Wetted

Referring to Figure 3.3-1b, the volume of each metal lump in cubic feet is calculated using:

[ ]+a, c

where

V(i,j,k) is the metal lump volume total for all loops. R_1 is the inner radius of the metal lump of interest and R_2 is the outer radius of the metal lump of interest.

For the first metal lump, R_1 is

[ ]+a, c

The heat capacitance for the metal lump is then calculated using

+a, c

where FMCPTM is an input multiplier as defined in Table 3.1-2 of Section 3.1

Next the initial heat transfer coefficients (UA) are calculated. UA(i,j,k) is defined as being from metal lump i to metal lump i-1. The UA is defined as being from the radial midpoints of lumps i and i-1.

+a, c

[ ] +a, c

where $r_1(i)$ is the inner radius of metal lump i.

Case c Cylindrical Metal Section with the Outer Surface Wetted

Referring to Figure 3.3-1c, the volume of each metal lump in cubic feet is calculated using:

[ ] +a, c

where

[ ] +a, c

Note that the metal lump volume is the total for all loops.

Given the initial temperature of the metal lumps, the metal specific heat (C_p), metal conductivity (k), and metal density (ρ_{metal}) are found using the properties as described in Section 3.2.

The mass of the metal lump is calculated using

[ ]+a, c

where FMCPTM is an input multiplier as defined in Table 3.1-2 of Section 3.1

Next the initial heat transfer coefficients (UA) are calculated. UA(i,j,k) is defined as being from metal lump i to metal lump i-1. The UA is defined as being from the radial midpoints of lumps i and i-1.

[ ]+a, c

[ ]+a, c

Case d Spherical Metal Section with Inner Surface Wetted

+a, c

Case e Irregularly-Shaped Metal Sections

Some metal of the RCS is irregularly shaped; e.g., some of the reactor vessel internals. These sections are treated as slabs, with the total thickness determined by the user as the total volume divided by the wetted surface area.

3.3.3 Thermal Time Constant

The thermal time constant (τ) between metal lumps is calculated next. [ ] +a,c

[ ] +a,c

+a, c

Figure 3.3-1a UA for Flat Metal slab

+a, c

Figure 3.3-1b UA for Cylindrical Metal Section with Wetted Inner surface

+a, c

Figure 3.3-1c UA for Cylindrical Metal Section with Wetted Outer Surface

3.4 Transient Calculations

[ ] +a,c

This solution technique was selected because (a) it is numerically stable for any size time step; (b) errors approach zero as the thickness and the time step approach zero; and (c) errors due to finite thickness and large time steps are always in the direction to minimize the heat transfer. Underprediction of the heat transfer causes a larger change in calculated fluid temperature, and is therefore conservative in the cases where the model is applied.

[ ] +a,c

Method C - Last Metal Lump in a Metal Section

[ ] +a, c

In calculating the heat transfer coefficient from the reactor coolant to the first metal lump in a metal section, [ ] +a, c

$Nu_D = 0.023\ Re^{0.8}\ Pr^{0.4}$

where

[ ] +a, c

Using the hydraulic diameter in inches

[ ]+a, c

The term, $Pr^{0.4}\,k/\mu^{0.8}$, is a state property, and can be determined as a function of pressure and temperature of the fluid.

4. Validation Calculations

Validation of the LOFTRAN thick metal model is made by comparing results to those calculated by RETRAN-02. RETRAN-02 is a one dimensional nodal network code reviewed and approved by the US NRC (see Reference 5).

Using LOFTRAN a feedwater line break transient typical of a Westinghouse four loop plant was simulated. In the analysis, only the thick metal mass heat transfer to the reactor vessel wall in the vessel inlet region was simulated. The vessel wall used the cylindrical metal section geometry with the inner wall wetted as described in Section 3. The vessel wall was divided into 4 radial metal lumps with thicknesses of 0.125 inches, 1.964 inches, 2.824 inches and 3.684 inches respectively. The first metal lump is stainless steel and simulates the cladding on the reactor vessel wall. The following three radial metal lumps use carbon steel properties. For simplification and conservatism the analysis assumes that the metal properties remains constant throughout the transient at values corresponding to the initial temperature.

For the RETRAN-02 calculations, a model of the reactor vessel inlet region and the vessel metal wall was set up. RETRAN-02 geometry was setup to be equivalent to that used in the LOFTRAN model. The vessel wall was simulated using 4 metal conductors with dimensional parameters corresponding to the 4 radial metal lumps used in the LOFTRAN model. Each of the metal conductors was divided into 5 subregions in each of the conductors. Thus, the vessel wall is modeled using a total of 20 radial metal subregions. Constant metal properties consistent with those used in the LOFTRAN analysis were used in the RETRAN-02 analysis. The transient LOFTRAN calculated fluid conditions (flow, pressure & enthalpy) as a function of time, entering the region adjacent to the vessel wall were input to RETRAN-02 as boundary conditions. A comparison of the transient fluid conditions are shown in Figures 4-1 through 4-3.

The thick metal mass heat transfer results of the LOFTRAN and RETRAN-02 cases are shown in Figures 4-4 and 4-5. Figure 4-4 compares the integrated energy transferred from the RCS fluid to the metal of the reactor vessel wall over a 1000 second time period. As shown in the figure the predicted energy removed from the reactor coolant by both codes is in very close agreement. Figure 4-5 compares the transient temperature distribution of the vessel wall for the two codes. The LOFTRAN temperatures represent the average temperature in each of the four metal lumps. The RETRAN-02 temperatures shown are the average temperature of the middle sub-region in each of the four conductors. The temperature predictions by both codes are very close.

The results of these cases demonstrate that the coding for the enhanced LOFTRAN thick metal mass heat transfer model is working correctly and as expected.

In applying the LOFTRAN enhanced metal heat transfer model in design basis heat up type analyses, the user can continue to include conservatism. The simplest methods for including conservatism are to neglect the metal mass of selected components or use constant metal thermal dynamic properties. To quantify the impact of using constant metal properties in LOFTRAN, the RETRAN-02 case from the previous section was rerun using metal properties which vary with temperature. The RETRAN-02 calculation again uses the LOFTRAN predicted RCS fluid boundary conditions shown in Figures 4-1 through 4-3. Figures 4-6 and 4-7 compare the LOFTRAN results with constant metal properties to those of RETRAN-02 with metal properties varied with temperature. Figure 4-7 compares the transient temperature distribution of the vessel wall for the two codes. The temperature predictions by both codes remain very close. Figure 4-6 shows that the heat absorption characteristics continue to follow similar trends. However, by using constant metal properties, LOFTRAN under predicts the metal heat absorption. Therefore, the results of heat up events such as a loss of normal feedwater or feedwater line break would continue to contain conservatism when the RCS thick metal mass heat transfer model is credited in LOFTRAN with constant metal properties.

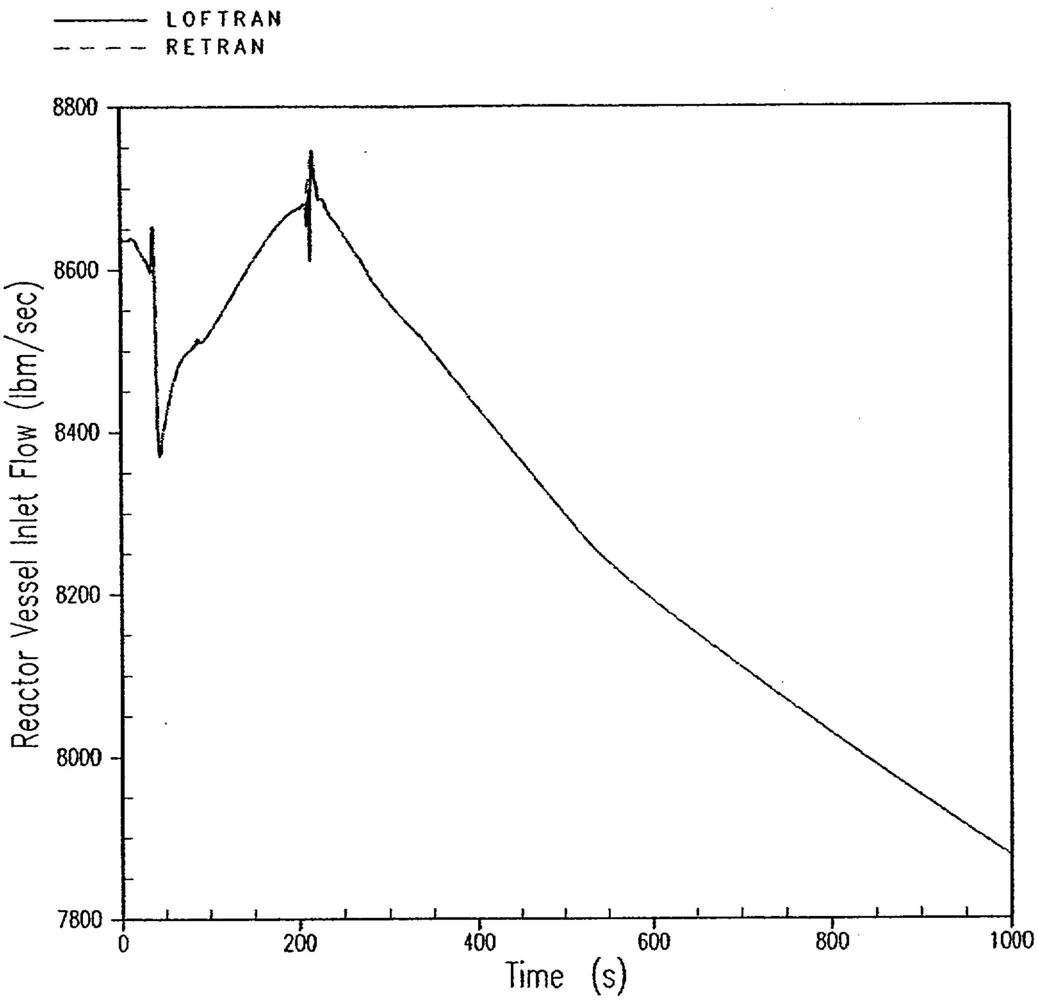

Figure 4-1 LOFTRAN Comparison to RETRAN

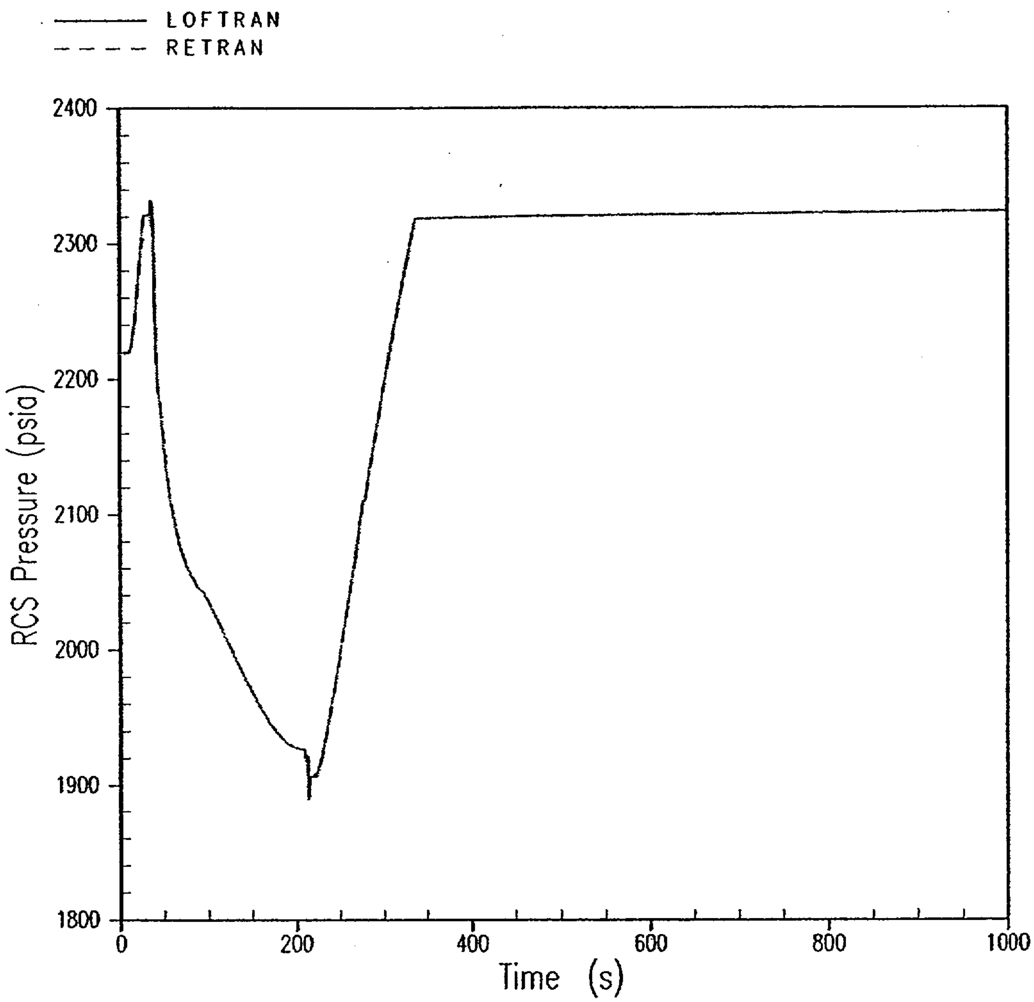

Figure 4-2 LOFTRAN Comparison to RETRAN

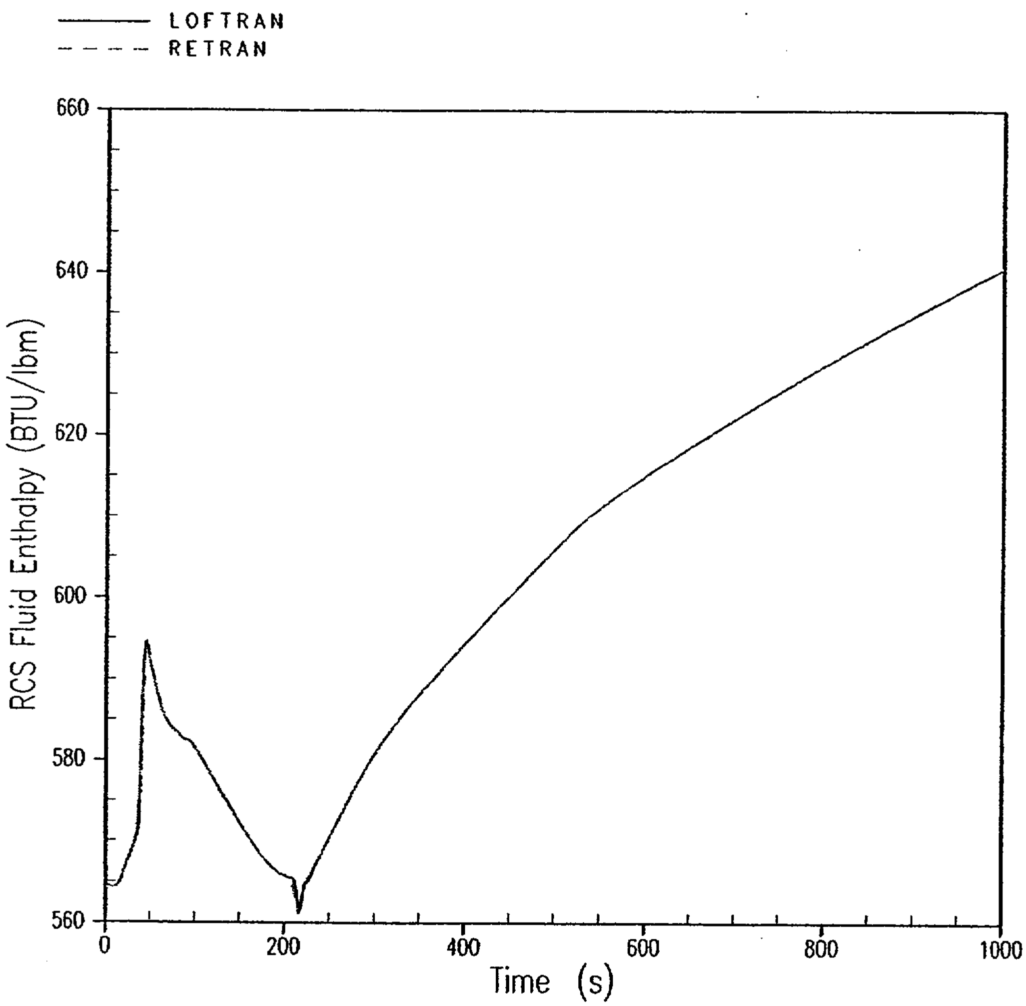

Figure 4-3 LOFTRAN Comparison to RETRAN

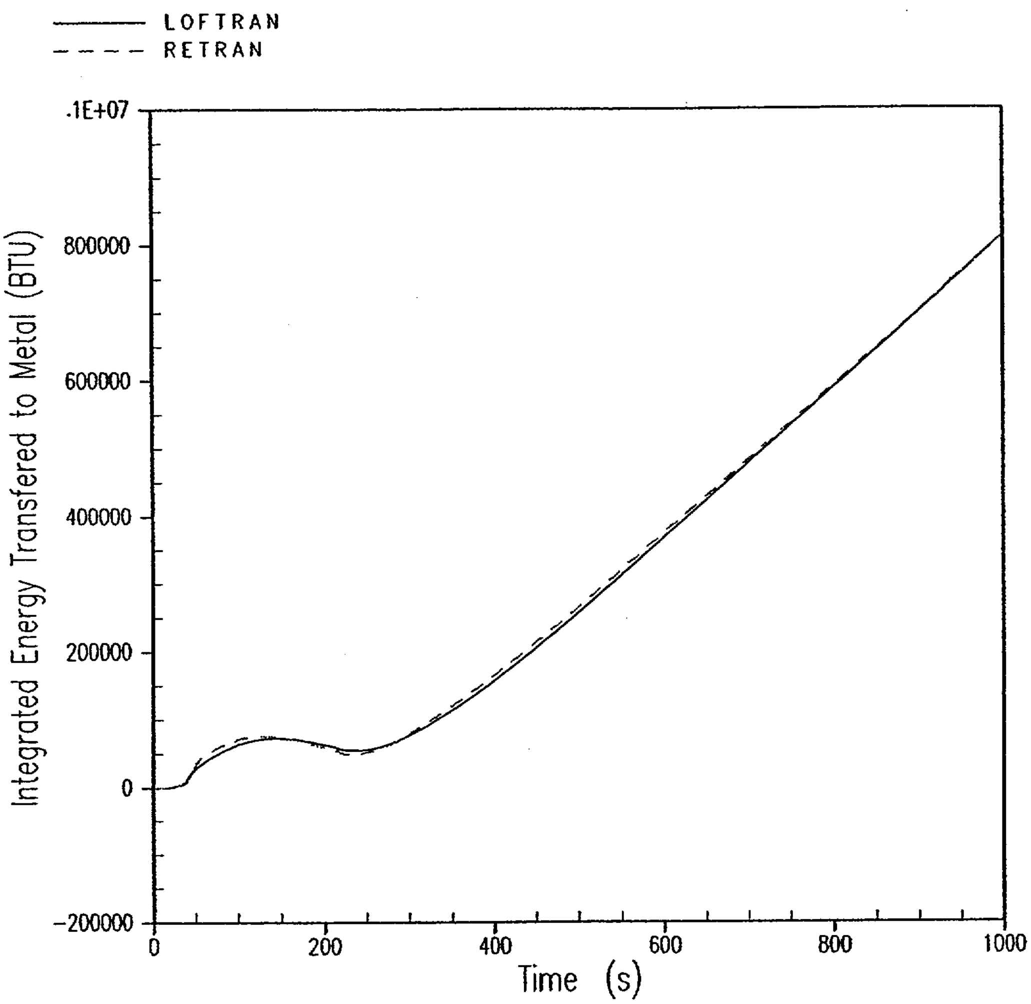

Figure 4-4 LOFTRAN Comparison to RETRAN (with constant metal properties)

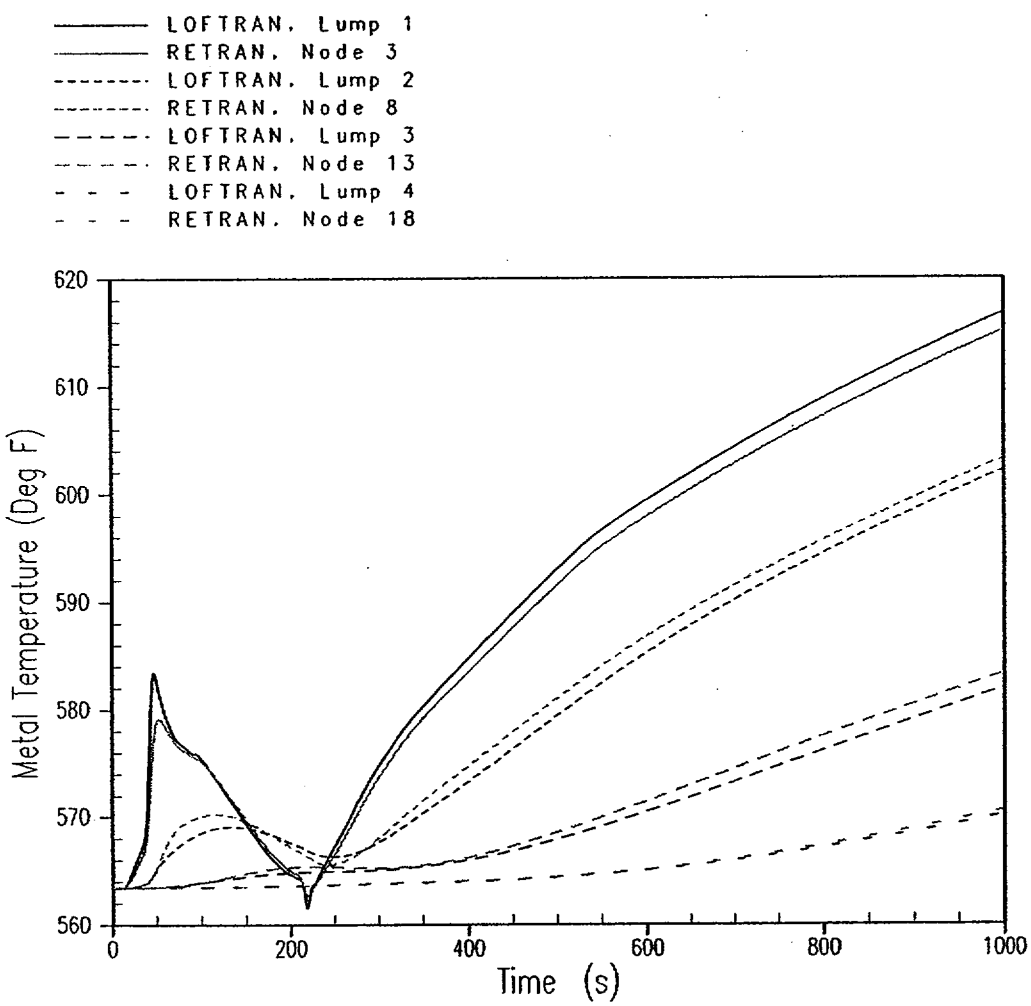

Figure 4-5 LOFTRAN Comparison to RETRAN (with constant metal properties)

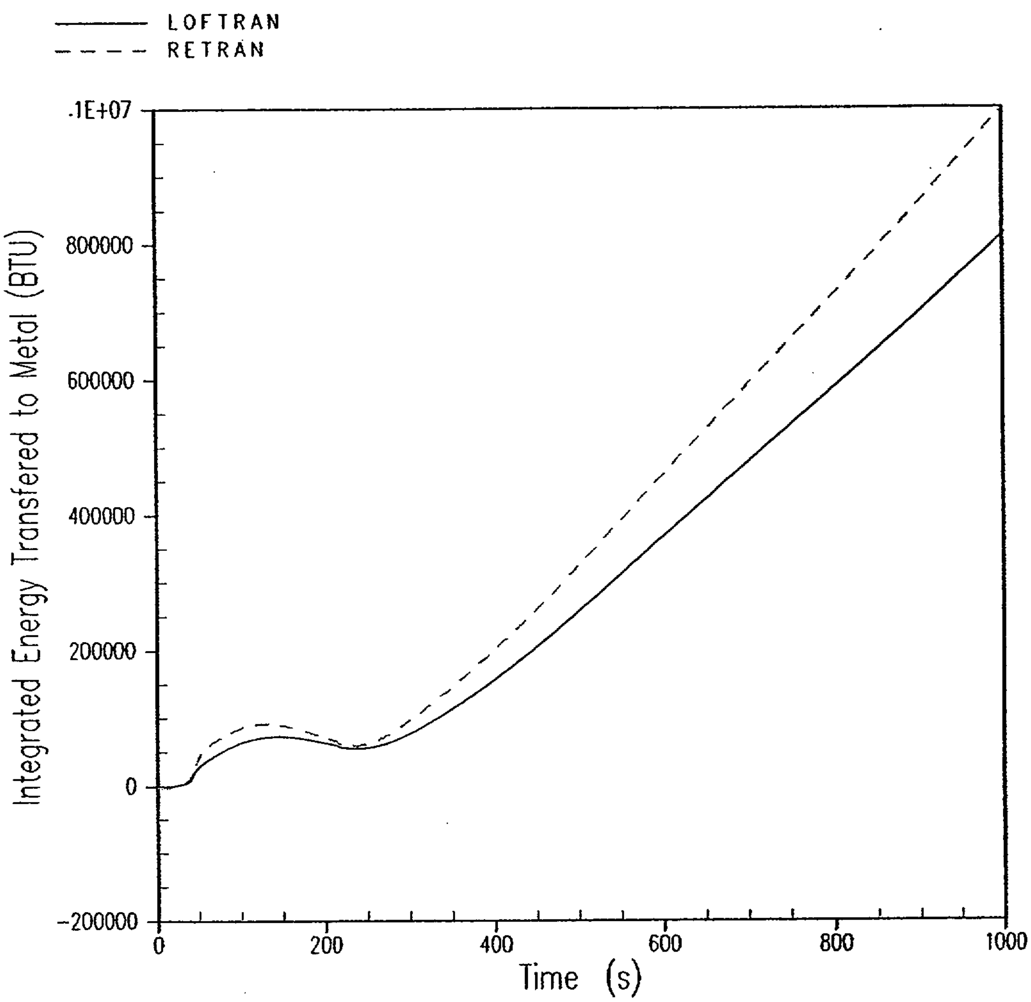

Figure 4-6 Comparison of LOFTRAN Using Constant Metal Properties to RETRAN Using Metal Properties Which Vary With Temperature

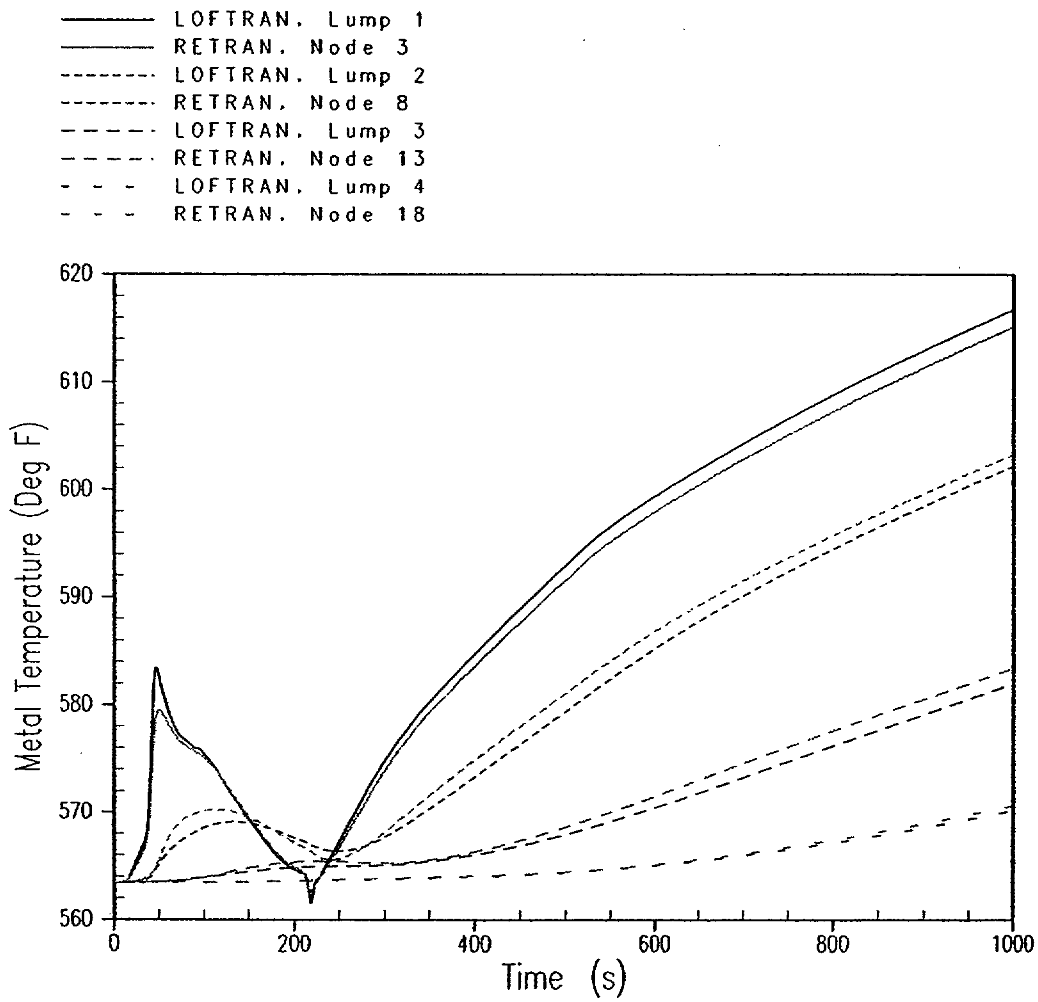

Figure 4-7 Comparison of LOFTRAN Using Constant Metal Properties to RETRAN Using Metal Properties Which Vary With Temperature

5. Conclusions

An enhanced RCS thick metal mass heat transfer model which is more detailed and accurate has been developed and incorporated into LOFTRAN. The enhanced model divides the RCS into seven RCS regions. Each region may then contain up to five metal sections to simulate five metal components with different geometry in the region. Each metal section is subdivided into up to four radial lumps. Preprogrammed metal thermodynamic properties may be used or metal properties may be supplied as input. Flat slab geometry or cylindrical geometry with the inner or outer surface may be used.

The enhanced model was verified by comparing the calculated results to those calculated using a more detailed RETRAN-02 thick metal heat transfer model. The LOFTRAN model results compare very favorably with those of RETRAN-02 validating the coding and demonstrating that the level of radial noding used in LOFTRAN is adequate. For simplicity and conservatism, constant metal properties may be used. A comparison RETRAN-02 results with temperature varying metal properties to those of LOFTRAN using constant metal properties indicates that the simplification of using constant metal properties results in less heat transfer from the RCS fluid to the RCS thick metal mass. For relatively slow heat up type events such as loss of normal feedwater or feedwater line ruptures, the assumption of constant metal properties yields slightly conservative results.

6. References

1 Burnett, T. W. T., et al., "LOFTRAN Code Description," WCAP-7907-P-A (Proprietary) and WCAP-7907-A (Nonproprietary), April 1984.

2 Land, R. E., "Mass and Energy Release Following a Steam Line Rupture," WCAP-8822, September 1976

3 Osborne, M. P., and Love, D. S., "Mass and Energy Releases Following a Steam Line Rupture Supplement 1 - Calculations of Steam Superheat in Mass/Energy Releases Following a Steamline Rupture," WCAP-8822-S1-P-A (Proprietary), September 1986

4 Dittus, F. W., and Boelter, L. M. K., University of California (Berkeley) Pub. Eng. Vol. 2, pg. 443, 1930

5 Huegel, D. S., et.al., "RETRAN-02 Modeling and Qualification for Westinghouse Pressurized Water Reactor Non-LOCA Safety Analyses," WCAP-14882-P-A (Proprietary), April 1999

6 American National Standards Institute N18.2, "Nuclear Safety Criteria for the Design of Stationary PWR Plants," 1973

ATTACHMENT 5

Meteorological Data Information
Supporting the Byron Station and Braidwood Station
Power Uprate License Amendment Request

The following information is provided in response to NRC questions.

1. Are the atmospheric dispersion (X/Q) factors in Table 6.7.1-2, "Offsite Breathing Rates and Atmospheric Dispersion Factors," of the Licensing Report new, or were they used previously in documents that have been submitted to the NRC for review, such as in the steam generator replacement amendment request several years ago?

   Response

   The atmospheric dispersion factors presented in Table 6.7.1-2 are part of the current Byron Station and Braidwood Station Design Basis and are not new values generated in support of the power uprate project.

2. Did the meteorological measurement program meet the guidelines of Regulatory Guide 1.23, "Onsite Meteorological Programs," from 1994 through 1998? Discuss checks made on the data to assure that the data input into the calculations were of good quality.

   Response

   From 1994 through 1998, the meteorological measurement program met, and currently meets, the guidelines of Regulatory Guide 1.23. Murray and Trettel, Inc. is under contract to Exelon Generation Company, LLC, to manage the meteorological monitoring program. Daily meteorological data transmission downloads are performed which are visually checked for accuracy based on known meteorological conditions. Weekly visits are made to the meteorological towers to check the equipment conditions. The meteorological tower instrumentation is calibrated quarterly. Murray and Trettel, Inc. has a comprehensive Procedures Manual, "P1009 Meteorological Monitoring Program, Equipment Servicing and Data Recovery Procedures Manual," which addresses both field and office procedures.

3. Discuss details of the methodologies, inputs and assumptions used to calculate new X/Q values.

   Response

   The computer code ARCON (i.e., Atmospheric Relative Concentrations in Building Wakes) input files and the hourly 1994 – 1998 meteorological data were provided in electronic format to the NRC on January 31, 2001. This data was used to calculate new control room X/Q values; however, as noted in the response to Question #1, the X/Q values found in Table 6.7.1-2 for the Exclusion Area Boundary (EAB) and Low Population Zone (LPZ) were not recalculated for the power uprate project.

4. Please provide, within several days if possible, an electronic copy of the hourly 1994 - 1998 meteorological data and a copy of the inputs used in making the new X/Q calculations?

   Response

   The ARCON input files and the hourly 1994 – 1998 meteorological data were provided to the NRC in electronic format on January 31, 2001.