**HISTORICAL TRENDS IN TANK 241-SY-101
WASTE TEMPERATURES AND LEVELS**

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September 1993

**Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

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MASTER

SUMMARY

The gas release and fluctuating level of the waste in tank 241-SY-101 have prompted more detailed interest in its historical behavior, in hopes of achieving a better understanding of its current status. To examine the historical behavior, essentially all of the tank waste temperature and level data record has been retrieved, examined, and plotted in various ways. To aid in interpreting the data, the depth of the non-convective waste layer was estimated by using a least-squares Chebyshev approximation to the temperatures.

This report documents the retrieval, critical examination, and graphic presentation of 241-SY-101 temperature and waste level histories. The graphic presentations clearly indicate a tank cooling trend that has become precipitous since late 1991. The plots also clearly show the decreasing frequency of waste gas release events, increasing height of the non-convective layer, and larger level drops per event.

ACKNOWLEDGMENTS

The author wishes to thank the following individuals: M. D. Northey of Westinghouse Hanford Company (WHC) for the idea of using commercial 3-dimensional plotting software to generate temperature contour plots, and for sharing his data; J. C. Cordero of Pacific Northwest Laboratory (PNL) for retrieving the temperature data, and patiently entering it into a database; E. I. Husa of WHC for transferring recent temperature and level data; and K. K. Anderson of PNL for sharing his reviewed, annotated level data.

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INTRODUCTION

Liquid wastes from the processing of nuclear materials have been stored in tank 241-SY-101 since 1977. Initially, only a limited amount of data was collected, consisting mostly of manual thermocouple readings and logbook entries. More data are available in recent years.

Various mitigation strategies to reduce flammable gas concentrations are being considered for Tank 241-SY-101 (as well as for other tanks with similar wastes). Also, changing behavior has been observed in Tank 241-SY-101 in recent years, consisting of a more rapid cooling trend and a lengthening of the period between gas releases. Therefore, examination of the 241-SY-101 temperature and waste level record became an important element in both understanding and predicting 241-SY-101 behavior.

TEMPERATURE RECORD

A thermocouple tree consisting of 18 thermocouples mounted in a 2-in. Schedule 40 pipe was originally installed in Tank 241-SY-101, and continued operating into September 1992. During the early days of tank farm surveillance, the main concern was with temperatures of the tank structure, and temperature readings were taken to ensure that temperatures remained below design limits and that no structural problems were developing. Typically, temperatures were recorded weekly, and only for every other thermocouple immersed in the waste (a total of 7 out of the 18). Readings were taken by switching to the appropriate thermocouple and manually recording its reading on a form developed for that purpose. This procedure was not always reliable (quality standards for the early data were not equal to those imposed since 1989), and bad data had to be culled from the record to select data for subsequent plotting (this is further discussed in the Temperature Data Transcription section below).

Since 1989, because of the heightened interest in hydrogen generation and periodic release from Tank 241-SY-101, data for all 18 thermocouples has been recorded by a data acquisition system. This was done spottily at first, and more frequently later, so that by mid-1990 daily (and sometimes even more frequent) readings were recorded.

Since September 1992, when a new tree (the so-called multi-functional instrument tree, or MIT) was installed to replace the old, considerably bent tree, 22 thermocouple readings have been available, typically on a daily basis. For a short period of time during September 1992, both trees operated simultaneously. Although the old tree was in riser 4A at a radius of 20 ft and the MIT is in riser 17B at a radius of 28 ft, the readings agreed quite well when adjusted for the bent angle of the old tree.

TEMPERATURE DATA TRANSCRIPTION

The early (1977-1989) temperature data record for Tank 241-SY-101 was located in storage in Seattle, and the boxes containing the record were retrieved. Because of the varying legibility of data entry (for example, on occasion a datum was crossed out and re-entered), it was felt that only a critical review and manual re-entry of these readings would provide a valid data base.

This data base was electronically transmitted to the author, who also examined it critically, discarding an entire 7-thermocouple data set if either of the following statements was true:

1. One or more thermocouple readings were missing from the data set.
2. One or more thermocouples exhibited anomalous readings, either in comparison with their companions, or with earlier or later data from other data sets. For example, a 10°F temperature drop of all readings in one day would be discarded as physically impossible (in overturn events, some readings go up, while others go down).

The data were then processed, using several spreadsheet and text editor programs, into a format acceptable to a sophisticated plotting program. Although other options are available, it was found easiest to format the data into a computer record (i.e., line) of input consisting of the triplet: day of year, thermocouple elevation, and thermocouple reading. (A complete data set for each year was thus assembled into a $D \times 7$ matrix, with D equal to the number of days with valid data in the year, by 7 elevations.) All the temperature and level measurement plots included herein were produced using a commercial 3-dimensional plotter program, with the exception of the non-convective layer height predictions.

For the temperature data beginning with 1990, when more frequent, voluminous, and higher quality data became available (e.g., thereafter all 18 thermocouples were recorded), manual sifting of the data became impractical. Several short FORTRAN programs were written to:

1. Select only a single data set per day. On many days, the thermocouples were read numerous times; some records consisted of multiple readings of a thermocouple, followed by multiple readings of the next one, and so on. The original raw data set was placed on a WHC file server, downloaded to a PC, copied to disk, and read from the disk into a workstation, which ran the data filtering programs.
2. Delete an entire day's record if any thermocouple readings were missing.
3. Examine in detail the filtered data record for each year, in the manner previously described.

The temperature data was then quickly plotted, to aid in further identifying and discarding any potentially bad data. The MIT data, consisting of 22 daily thermocouple readings beginning in September 1992, were treated in similar fashion.

LEVEL RECORD

The level of the crust in Tank 241-SY-101 has been measured in three ways: with a Food Instrument Corp. (FIC) contact sensor, with a manual tape, and with radar. At times, all three methods were employed simultaneously; the data recorded are frequently inconsistent. Level readings can be affected by floating objects, such as detached pieces of crust (FIC and radar readings would be most affected). Manual tapes can provide erroneous values due to the

temporary sticking of waste "stalactites" to the tape, giving a fictitiously high waste level indication.

The level data through 1991 had previously been finely examined and sifted by K. K. Anderson, who supplied the author with these data files and notes on such items of interest as lancements. More recent level data was placed on a WHC file server by E. I. Husa, and downloaded to my workstation (it has not yet been plotted).

LEVEL DATA TRANSCRIPTION

Because the level data were not in a consistent format, they had to be edited, using several editors, to adapt them for input into the data plotter program.

TEMPERATURE AND LEVEL PLOTS

The temperature and level plots contained herein were modeled after the plotting style suggested by the work of M. D. Northey of WHC, where temperature ranges are represented by differing shades of color. The plots are as follows:

1. Figures 1 - 5 show combined level/temperature plots for each year, from 1980 through 1991, plus additional temperature plots for 1992 and 1993. Note that the tank was not filled completely until 1980. The upper part of each figure shows the waste level measured; the middle part shows the temperatures measured for 7 thermocouples; and the lower part shows the calculated height of the non-convective waste layer (the calculation method is described below).
2. Figures 6 and 7 display temperature "maps," starting with initial fill in 1977 and ending with recent data. Blank areas have purposely been inserted to identify years with data of little value (1978-1979).
3. Figures 8 and 9 show the entire level record (through 1991) and the data since 1980 on a finer scale, respectively (data from 1992 to the present has been adequately plotted by others at both WHC and PNL).
4. Figures 10 - 24 contain expanded temperature plot pairs for individual years. Typically, the first plot of the pair (the "a" figure) shows a 2-dimensional contour rendering; the second plot ("b") presents the identical data in a 3-dimensional format for easier identification of such features as gas release events. For 1990, temperatures from the 7-thermocouple manual form records (Figure 21a) and the entire 18-thermocouple data acquisition record (Figures 21b and 21c) are both available. In 1992, the MIT data (Figures 23c and 23d) supplants the old thermocouple tree data (Figures 23a and 23b).

NON-CONVECTIVE LAYER HEIGHT INDICATIONS

One change that has been observed over time (and is clearly visible in the temperature plots), is the variability in the height of the non-convective waste layer (NCL) at the bottom of Tank 241-SY-101. The non-convective layer is so-called because its temperature profile often shows a higher-temperature parabolic section below a constant-temperature section. A parabolic profile is characteristic of a heat-producing non-convective medium. Recent indications were that the height of the NCL was about 250 in., and increasing. Although the height of the non-convective layer can be estimated visually from the plots, or directly from perusing the data, a more consistent approach was desired. Accordingly, a short FORTRAN code was written that calculates the level of the top of the non-convective layer.

In greater detail, the NCL level is calculated in five steps:

1. The code reads in the appropriate annual temperature history file, containing the final, edited temperature plot data.
2. Starting with a thermocouple just above the approximate level of the NCL, temperatures are compared in pairs, and the upper temperature is discarded if it is close to the lower one, i.e., if the two temperatures are within 1.5°F of each other. For the early data when only 7 readings were taken, the starting thermocouple is the uppermost one; when all 18 thermocouple readings are available, the starting thermocouple becomes #12, the fifth one from the top, 270 in. from the tank bottom; for the MIT tree with its 22 thermocouples, the starting thermocouple becomes #16, 268 in. from the bottom (starting the calculation at MIT thermocouple #17 appeared to have a very small effect on 1992 calculation results, and none on 1993 results). This process generates temperature data sets that are entirely from within the non-convective layer.
3. The temperature measured by the lowest of the convective layer thermocouples is selected as representative of the temperature in that layer (temperature variation in the NCL is so small that temperature averaging did not affect calculation accuracy).
4. It was assumed that a parabolic temperature profile, which is representative of a medium with combined heat generation and pure conduction, exists in the non-convective layer. The data was fit to a polynomial equation of second degree (a parabola). In practice, the Chebyshev form of the polynomial equation was employed, because it leads to better accuracy in a least-squares polynomial approximation to the data. Curve fitting was accomplished by a mathematical library routine that returned the 3 desired coefficients. This solution provided temperature (the parabola) as a function of height; to obtain height at a specific temperature (see #3 above), the resulting quadratic equation was solved in the standard manner.
5. Bad data were discarded (e.g., fewer than 3 temperatures for a given data set; or skewed temperature profiles that were far from parabolic and resulted in a divide by zero).

The non-convective layer heights predicted in this manner are shown in Figures 25 - 37, (and in Figures 1 - 5, described above). The height of the non-convective layer calculated by the method just described is identified by an asterisk (e.g., 200 in.*) in the rest of this report.

DATA ANALYSIS AND INTERPRETATION

In interpreting the temperature readings, it should be remembered that the data source at any given time was only a single thermocouple tree within the tank. The discussion below implies that the temperature record is representative of the entire tank, but this is not known to be true. There may well be radial temperature variations, and different vertical temperature profiles may exist at other locations within the tank.

An examination of the attached temperature and level history plots reveals some interesting features and trends. After complete filling in 1980, the tank contents were quite hot, about 140°F, and there was little vertical variation in temperature. However, non-isothermal conditions became the norm within a year, indicating that small gas release events (GREs) were occurring, with a period of about 30 days.

In 1982, level drops increased in magnitude over earlier years; and a distinct, hot, non-convective layer became established by mid-year. Water lancing, begun in the mid-80s, seems to have affected the waste in Tank 241-SY-101 in two ways: the cooling trend was accelerated, and the gas release events became less frequent (about every 80 days) and more violent (i.e., the level drops were larger at each event than previously). As one would anticipate, the GRE mechanism also increased the pre-event level of the waste somewhat.

Air lancing in 1988 and 1989 followed the water lancing, with similar, even more exaggerated consequences. The lancements also tended to homogenize the wastes, leading to less distinct convective and non-convective regions. Air lancing was stopped when tank waste attained a very high level (about 425 in.).

After the lancements were stopped, the waste again separated into distinct convective and non-convective regions, and the waste level began to drop. But the temperature decline noted during the lancements continued, and accelerated even more. A precipitous temperature decline occurred at the time of the December 1991 gas release event and rollover. This cooling continues now at that same steep rate, considerably higher than the 1.3°F/year (WHC-SD-WM-SAR-046, p. A-11) that is a consequence of the decrease in activity of the radioactive isotopes in the waste. The period between gas release events has continued to lengthen, and currently is well over 100 days.

Before the lancements began, the non-convective region grew slowly, from a level of about 130 in.* in 1981 to about 185 in.* in early 1986. The level decreased during lancing, so that by early 1989 when lancing ceased, it was back to about 130 in.* The height of the non-convective region has steadily increased since then. This trend is clearly visible in Figures 25 - 37, which are plots of the non-convective layer height predictions using the Chebyshev polynomial extrapolation described earlier. The predictions are "noisy" largely because all temperature data were used, even when no distinct convective/non-convective demarcation existed. Currently, as indicated by

Figure 37, the non-convective region height is at about 250 in.*, a record height. The estimated average non-convective layer height is summarized in Table 1:

TABLE 1. Estimated Average Height of NCL

Year	NCL Height,* in.
1981	130
1982	170
1983	160
1984	180
1985	170
1986	170
1987	180
1988	130
1989	160
1990	180
1991	210
1992	≈220
1993	255

* Average values shown are just prior to GREs, as calculated by Chebyshev polynomial extrapolation.

THEORIES AND MODELS

Various theories and models have been proposed to account for the behavior of the waste in Tank 241-SY-101. These theories and models, including some suggested by the author, are presented in Table 2.

SUGGESTED FOLLOW-ON WORK

It is suggested that initial follow-on activities entail a critical examination of the theories and proposed schemes listed in Table 2. Further activities should consider the implications of the observed phenomena on gas production and release events, how these might impact safety, and

TABLE 2. Tank 241-SY-101 Behavior Models

Observed Phenomenon	Theory/Model	Proposed Verification
Waste Cooling Trend	Decrease in chemical heat	Re-evaluate chemistry
	Radioactive species different than assumed	Re-evaluate species present in waste
	Increased heat transfer rate	Consider changes in waste; earth moisture
	Increased air flow rates in dome and annulus	Calculate heat loss, based on current flow rates
Growth of NCL	Location of thermocouple tree	Data from second MIT tree may help
	Change in waste characteristics	Re-evaluate waste rheology
Increased period between GREs	Change in waste characteristics	Re-evaluate waste rheology
	Cooling trend	Re-evaluate waste rheology

mitigation strategies. More specifically, it is recommended that the TEMPEST code be used for waste heat transfer modeling. TEMPEST can handle the 3-dimensional heat transfer and convection that occurs in the waste, but some complexities of the tank geometry would have to be treated as lumped coefficients in the preliminary 2-dimensional model. For example, a loss coefficient through the bottom wall would represent the cooling air channels. At first, the analyses should consist of correctly predicting past temperatures, starting from the initial conditions of 1980 (this may be too ambitious; a more reasonable starting point might be the end of the lancing period, in 1989). Thereafter, the model could be used to predict future trends, and to evaluate the impact of mitigation strategies.

As noted earlier, the temperature and level records plotted in this report are based on data sets that were reconstructed by filtering the raw data records. These records are available in electronic form, in various versions from raw data to fully edited, and are available upon request to the author of this report.

CONCLUSIONS

Retrieval, plotting, and analysis of the waste temperature and level historical record for Tank 241-SY-101 has provided clear evidence of several disquieting trends that were previously only suspected. Various theories have been proposed to explain these trends. These theories need to be tested, preferably with the TEMPEST code.

FIGURE 1. Waste Levels and Temperatures, 1980-1982

Tank 101SY Temperature History for 1983

Tank 101SY Temperature History for 1984

Tank 101SY Temperature History for 1985

FIGURE 2. Waste Levels and Temperatures, 1983-1985

(20) is Point 8 day/night/avg pH

(20) is Point 8 day/night/avg pH

Tank 101SY Temperature History for 1986

Tank 101SY Temperature History for 1987

Day
Day

FIGURE 3. Waste Levels and Temperatures, 1986-1987

Tank 101SY Temperature History for 1988

Tank 101SY Temperature History for 1989

Tank 101SY Temperature History for 1990

FIGURE 4. Waste Levels and Temperatures, 1988-1990

Data for 1992-1993 Not Plotted

Tank 101SY Temperature History for 1991

Tank 101SY Temperature History for 1992 - MIT

Tank 101SY Temperature History for 1993

FIGURE 5. Waste Levels and Temperatures, 1991-1993

Data for 1978-1979 Not Plotted

Tank 101SY Temperature History for 1980

Tank 101SY Temperature History for 1983

Tank 101SY Temperature History for 1981

Tank 101SY Temperature History for 1984

Tank 101SY Temperature History for 1982

Tank 101SY Temperature History for 1985

FIGURE 7. Waste Temperatures, 1986-1993

FIGURE 8. Waste Levels, 1977-1991

FIGURE 9. Waste Levels, 1980-1991

FIGURE 10a. Waste Temperature Contours, 1977

FIGURE 10b. 3-Dimensional Waste Temperature Contours, 1977

FIGURE 11a. Waste Temperature Contours, 1980

FIGURE 11b. 3-Dimensional Waste Temperature Contours, 1980

FIGURE 12a. Waste Temperature Contours, 1981

FIGURE 12b. 3-Dimensional Waste Temperature Contours, 1981

FIGURE 13a. Waste Temperature Contours, 1982

FIGURE 13b. 3-Dimensional Waste Temperature Contours, 1982

FIGURE 14a. Waste Temperature Contours, 1983

FIGURE 14b. 3-Dimensional Waste Temperature Contours, 1983

FIGURE 15a. Waste Temperature Contours, 1984

FIGURE 15b. 3-Dimensional Waste Temperature Contours, 1984

FIGURE 16a. Waste Temperature Contours, 1985

FIGURE 16b. 3-Dimensional Waste Temperature Contours, 1985

FIGURE 17a. Waste Temperature Contours, 1986

FIGURE 17b. 3-Dimensional Waste Temperature Contours, 1986

FIGURE 18a. Waste Temperature Contours, 1987

FIGURE 18b. 3-Dimensional Waste Temperature Contours, 1987

FIGURE 19a. Waste Temperature Contours, 1988

FIGURE 19b. 3-Dimensional Waste Temperature Contours, 1988

FIGURE 20a. Waste Temperature Contours, 1989

FIGURE 20b. 3-Dimensional Waste Temperature Contours, 1989

FIGURE 21a. Waste Temperature Contours, 1990 (7 thermocouples)

FIGURE 21b. Waste Temperature Contours, 1990 (18 thermocouples)

FIGURE 21c. 3-Dimensional Waste Temperature Contours, 1990

FIGURE 22a. Waste Temperature Contours, 1991

FIGURE 22b. 3-Dimensional Waste Temperature Contours, 1991

FIGURE 23a. Waste Temperature Contours, 1992 (18 thermocouples)

FIGURE 23b. 3-Dimensional Waste Temperature Contours, 1992 (18 thermocouples)

FIGURE 23c. Waste Temperature Contours, 1992 (22 thermocouples)

FIGURE 23d. 3-Dimensional Waste Temperature Contours, 1992 (22 thermocouples)

FIGURE 24a. Waste Temperature Contours, 1993

FIGURE 24b. 3-Dimensional Waste Temperature Contours, 1993

FIGURE 25. Calculated Waste Non-Convective Layer Heights, 1981

FIGURE 26. Calculated Waste Non-Convective Layer Heights, 1982

FIGURE 27. Calculated Waste Non-Convective Layer Heights, 1983

FIGURE 28. Calculated Waste Non-Convective Layer Heights, 1984

FIGURE 29. Calculated Waste Non-Convective Layer Heights, 1985

FIGURE 30. Calculated Waste Non-Convective Layer Heights, 1986

FIGURE 31. Calculated Waste Non-Convective Layer Heights, 1987

FIGURE 32. Calculated Waste Non-Convective Layer Heights, 1988

FIGURE 33. Calculated Waste Non-Convective Layer Heights, 1989

FIGURE 34. Calculated Waste Non-Convective Layer Heights, 1990

FIGURE 35. Calculated Waste Non-Convective Layer Heights, 1991

FIGURE 36. Calculated Waste Non-Convective Layer Heights, 1992

FIGURE 37. Calculated Waste Non-Convective Layer Heights, 1993

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