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Ideas and Concepts for Diagnosis of Performance and Evaluation of Data Reliability Based Upon ARSA State-of-Health (SOH) Data

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Ideas & Concepts for Diagnosis of Performance and Evaluation of Data Reliability based upon ARSA State-of-Health (SOH) data

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March 1, 2000

At the current time, the Pacific Northwest National Laboratory (PNNL) prototype for the Automated Radioxenon Sampler/Analyzer (ARSA) automatically transmits, on a daily basis, a subset of all state-of-health (SOH) data in an e-mail data file to a limited number of recipients. These variables represent what were considered the most critical physical parameters for the ARSA's operation at the beginning of the field demonstration in Freiburg, Germany. Operators at PNNL perform a daily review of the information in the data file for anomalous operational conditions as evidenced by sensor readings. The initial review is easily implemented by plotting the various sensor data versus time and looking for gross deviations in the periodicity of the variables compared to previous sample sensor data. After viewing the 24-hr graphical plots, if necessary, a review is conducted of the tabular data of specific sensor anomalies. In most cases, our experience has been that when there is an ARSA operational problem the data file will have multiple sensor readings that reflect some aspect of the problem.

For example, there have been a series of short intervals over the period mid-January to mid-February, 2000, where the flow through the air collection mass-flow controller (MFC-1) drops below the nominal 100 liters/minute. If the decrease in flow is maintained over more than a few minutes, there is normally an impact on other components of the ARSA. Specifically, the air chiller output temperature will increase, as will the post-collection radon trap temperature (when in cooling mode). Also, the temperature of the final charcoal trap will increase, if it is in a cooling mode, and after several minutes temperatures in the pre-radon trap and main charcoal trap that are currently in the sampling mode will increase. Additionally, if there is a period of zero flow due to valve closure (from power supply failures) and the time interval is long enough (approximately 5 minutes or longer), the pressure in the main charcoal trap in sampling mode will increase due to warming. Such an event is easily determined from visual inspection of the SOH variables.

Attached are graphical plots, Figures 1 through 4, of the data file that was e-mailed January 26, 2000 where a sizeable "flow anomaly" occurred at more than one period during the day, illustrating the points discussed. These anomalies were readily noted in a cursory data review process using graphical plots generated within Microsoft® Excel. Figure 1 contains mass flow sensor data and clearly shows two intervals where MFC-1 flow dropped from normal flow of 100 liters per minute to near zero. The other two mass flow controllers, with flow rates of 200 to 400 cc/min, follow typical cyclical behavior observed in previous and more recent data files over the 24-hour data file time period.

Figure 2 displays four temperatures, including the chiller output temperature (ts-5), the final charcoal trap (ts-21), and the two post-radon traps (ts-17 & ts-19). The flow anomaly clearly impacts the chiller output temperature during both flow anomalies, as evidenced by the increase in temperature from near -100°C to approximately -50°C in the second instance of flow disruption. But there are no apparent affects upon the other sensor temperatures shown in this graph, since neither of the two post radon traps nor the final charcoal trap were in cooling mode at the time of flow disruption.

Figure 3 displays pressure versus time over the 24-hour length of the data file for the two main charcoal traps and the pressure after the ascarite trap module (process two pressure in operational nomenclature). There is an increase in internal pressure in the main charcoal trap

during the second flow disruption, since the pressure on sensor ps-5 is observed to increase to 50 psig. There may also be a slight increase in main charcoal trap pressure (ps-4) associated with the first flow disruption; however, it is not as obviously apparent.

Figure 4 displays temperature sensor data for the pre-radon traps and the main charcoal traps within the ARSA. The first flow disruption appears to have influenced sensors ts-9 and ts-7, associated with the traps in the sampling mode, since there appears to be a slight increase in temperature from approximately -80 C. Sensors ts-11 and ts-13 appear to have been influenced by the second flow disruption, since they rise from approximately -80 C and -90 C, respectively, 10 degrees Centigrade or more.

The information contained in the SOH file can therefore be used to verify routine operation within normal parameters when such is the case. Alternatively, the data in the SOH file can often be employed to determine a cause for problems in samples or data such as lowered xenon yield and/or a level of radon higher than normal. It must be kept in mind, however, that the rate at which the data is collected for the ARSA SOH variables is on a two-minute interval (though programmable down to 2 sec). Thus a problem that occurs over an interval shorter than that time may not be evident upon review of the file. However, most significant problems affecting data quality and reliability of operation will be evident in the 2-minute interval data file.

If there are no anomalous data observed in the SOH file, the radioxenon data acquired from the sampling over the SOH interval should be accepted as coming from normal gas collection, purification, and transfer. If, however, anomalous operational data are observed in the SOH file, the data in the associated radioxenon files should be examined more carefully, since higher radon concentrations or lower stable xenon yields might be associated with the deviation from normal operational conditions. The minor flow fluctuations observed to date have not apparently had an impact upon radioxenon data quality during the experimental period in Germany.

Use of SOH data for predictive diagnostics

We currently utilize the SOH data to review system performance over a previous period. However, it is conceivable that the data in the file could be employed for detection of minor problems prior to the point at which they significantly impact data quality. The most obvious example is the nitrogen carrier pressure. One can readily track the decrease in nitrogen-cylinder pressure versus time and extrapolate the date when a new cylinder will be required. There are several other potential measures that could be employed to identify minor deterioration in operational performance prior to a major failure. These are discussed in the paragraphs below under the specific ARSA component monitored by a sensor or sensors. Although we have not yet predicted a failure in a major ARSA component, there are a few examples of sensors/readings that, if sufficient resources were put into it, might give some indication of the ARSA's possible future state-of-health:

- Compressors
- Vacuum pump
- Heaters lifetime
- Ascarite expenditure
- Dewpoint measurement
- Air chiller

Compressors

It is possible that the status of the main compressor might be tracked over time by examining the pressure fluctuations, a measure of pump cycle time, in the main charcoal traps during sampling. If the time to reach shutoff pressure increases, this may well indicate the pump performance is deteriorating. The specific cause of deteriorated performance would require additional review of sensor data, or perhaps an onsite investigation. Pump wear and air leak(s) are two potential

problems that would appear as deteriorated performance. One can also examine the current flow when the compressor is on and possibly the temperature of the compressor to verify any minor problem before catastrophic failure occurs.

Vacuum Pump

It may be possible to evaluate vacuum pump health by tracking the vacuum pressure at some standard point in the ARSA operational cycle versus time. If the vacuum level deteriorates over time, days or a week, it would point to a need for maintenance in the near future. Vacuum pump performance may also be evaluated through the low temperature achieved when a main charcoal trap is being evacuated immediately after sampling. If this temperature trends upward over numerous cycles, it may be a diagnostic of deteriorating vacuum pump capability. Again two alternative causes for deteriorating performance are pump wear and leak(s).

Heaters

It may be possible to evaluate the health of the several heaters in the ARSA by using the trend versus time (over days, weeks, or months) of the period required to reach the specified temperature. Alternatively, a long-term record of the current being drawn by the heaters during the on cycle may also prove to be predictive. Also the slope of temperature increase versus time when the heater comes on during regeneration intervals might be an indicator of heater health, when tracked over substantial operational periods.

Ascarite Traps

We have seen that it is possible to diagnose the time at which an ascarite trap needs to be changed through the use of multiple parameters. The presence of elevated carbon dioxide in final samples, and/or the buildup of a pressure drop across the ascarite (carbon-dioxide removal) module are indicative of the need for ascarite module replacement. The presence of an elevated pressure drop during elution can be ascertained by comparing the pressure in the main charcoal trap to the pressure downstream of the ascarite trap (process two pressure sensor).

Dewpoint Measurement

A trend of the dewpoint of the system air over substantial periods of operation may determine a potential deterioration of dryer column media. Dewpoint will fluctuate over periods of hours to days depending upon temperatures and humidity; however, examining longer term trends over weeks to months may be useful to diagnose adsorbent health. It is possible, however, that shorter-term fluctuations associated with ambient temperature and humidity changes will obscure any longer term trend.

Air Chiller

We have to date, not had any problems with the chiller employed in the ARSA, though tracking the long-term output temperature trend might indicate unit deterioration prior to catastrophic failure. Like the dewpoint, there will be normal fluctuations in chiller output temperature based upon variations in the room temperature, and these "normal" operational fluctuations might well obscure a much smaller increase in temperature associated with deteriorating unit performance over a period of days to even weeks. As mentioned above for the main air compressor, monitoring current demand or motor temperature of the chiller might be other useful diagnostics over substantial operational periods to indicate minor deterioration in performance. A long-term trending should be useful to diagnose minor deterioration in performance prior to a major operational failure.

Conclusions

All of the sensors mentioned above are powerful diagnostic tools currently, and have the potential to become predictive tools. As of yet, however, the ability to predict major equipment failures has not been demonstrated. We feel that with proper attention and more operating time, however, predictive algorithms may be developed, and we are beginning to investigate some of these.

A useful software tool for the IMS would be an automated program that searched the incoming ARSA SOH files each day. The automated software program could be designed to produce an easy to read report listing any deviations in the SOH parameters that are indicative of an early warning or any degradation in performance that might otherwise not be observed. An example might be a warning if the chiller output temperature rose over some nominal limit, say 5 degrees Centigrade during the 24-hour period. Another example might be a warning if the dewpoint rose over a nominal limit of perhaps 10 degrees Centigrade. A more sophisticated approach might entail establishing two 24-hour "templates" for the various sensors on an ARSA unit and setting various statistical deviation limits for the triggering of warning flags to data reviewers. Two templates would be required because there are 3 samples per day on a dual trap system. The day one template would contain data for a sequence of samples for trap A, trap B, and trap A, day two would contain the sequence trap B, trap A, and trap B and day three would contain the sequence trap A, trap B, trap A (day 1 sequence repeated). After a longer operational history is developed for the ARSA the data will likely allow establishment and evolution of fairly sophisticated diagnostic software for determining the "health" of individual field units and thus the reliability of data generated from the unit.

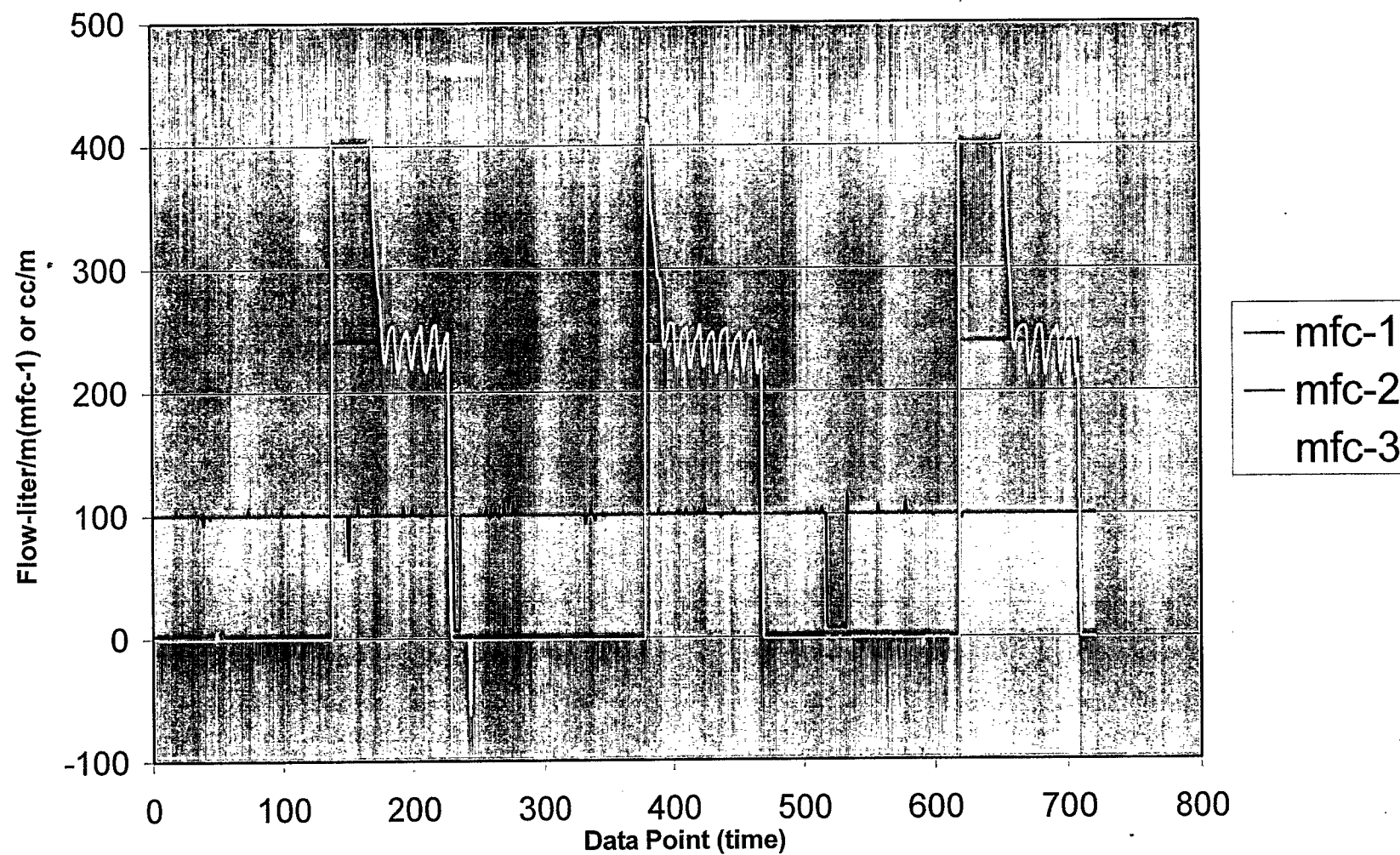


Figure 1. ARSA Sample, Nitrogen, and Elution Mass Flow Controller Readings for a 24-hour SOH file

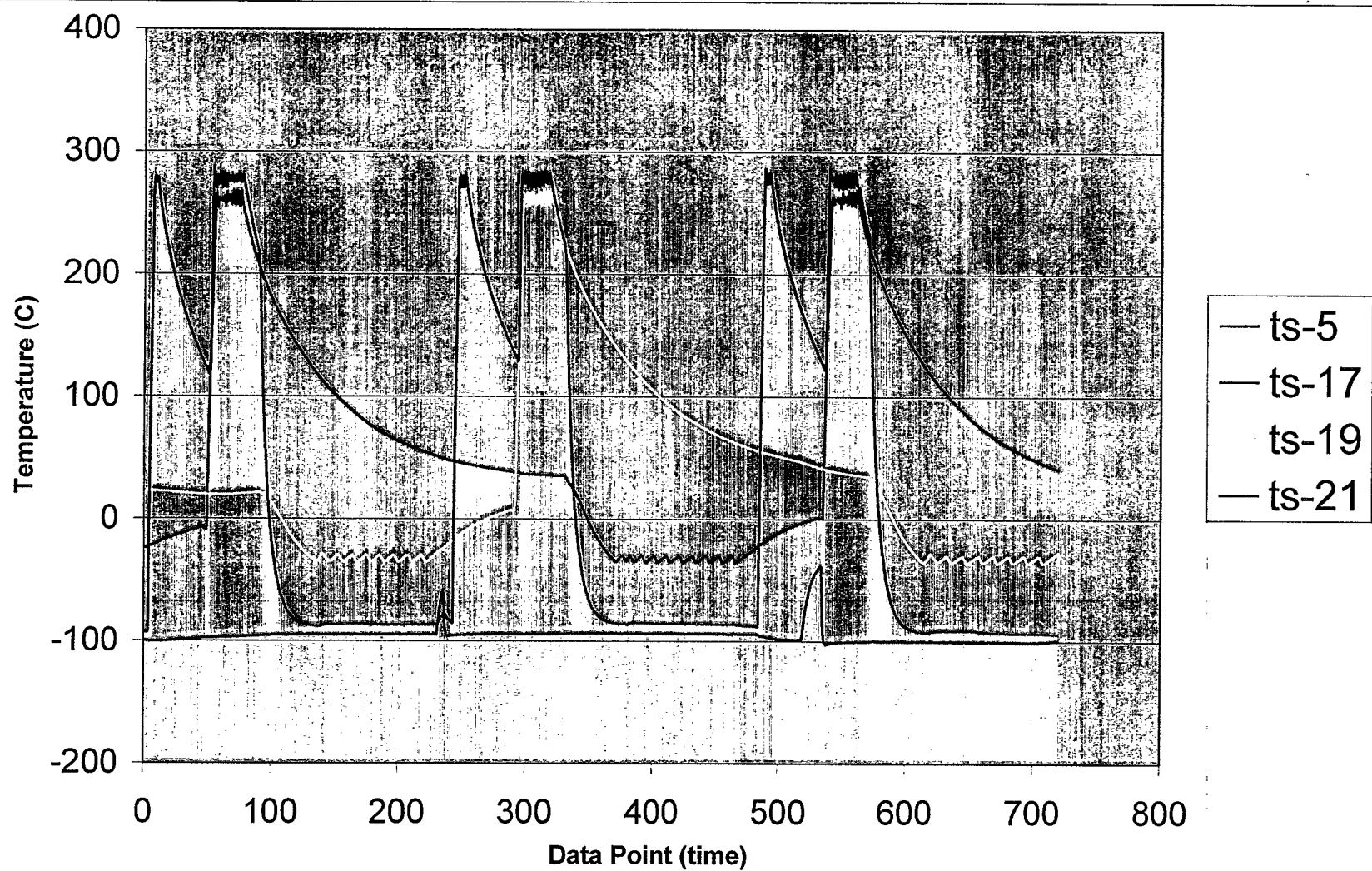


Figure 2. ARSA Chiller Output, Post Radon Trap, and Final Trap Temperature Sensor Readings for a 24-hour SOH file

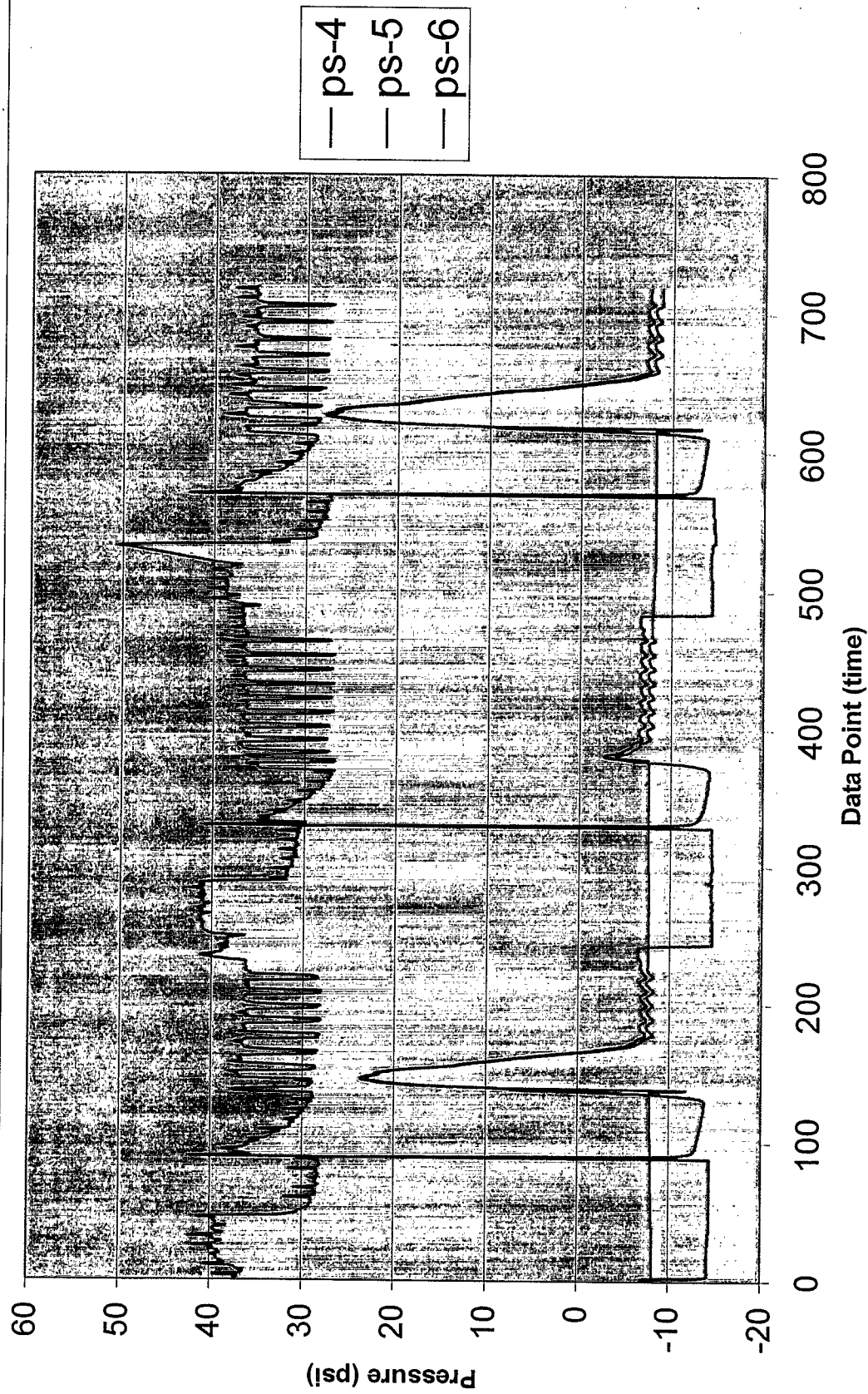


Figure 3. ARSA Main Trap and Process 2 Pressure Sensor Readings for a 24-hour SOH file

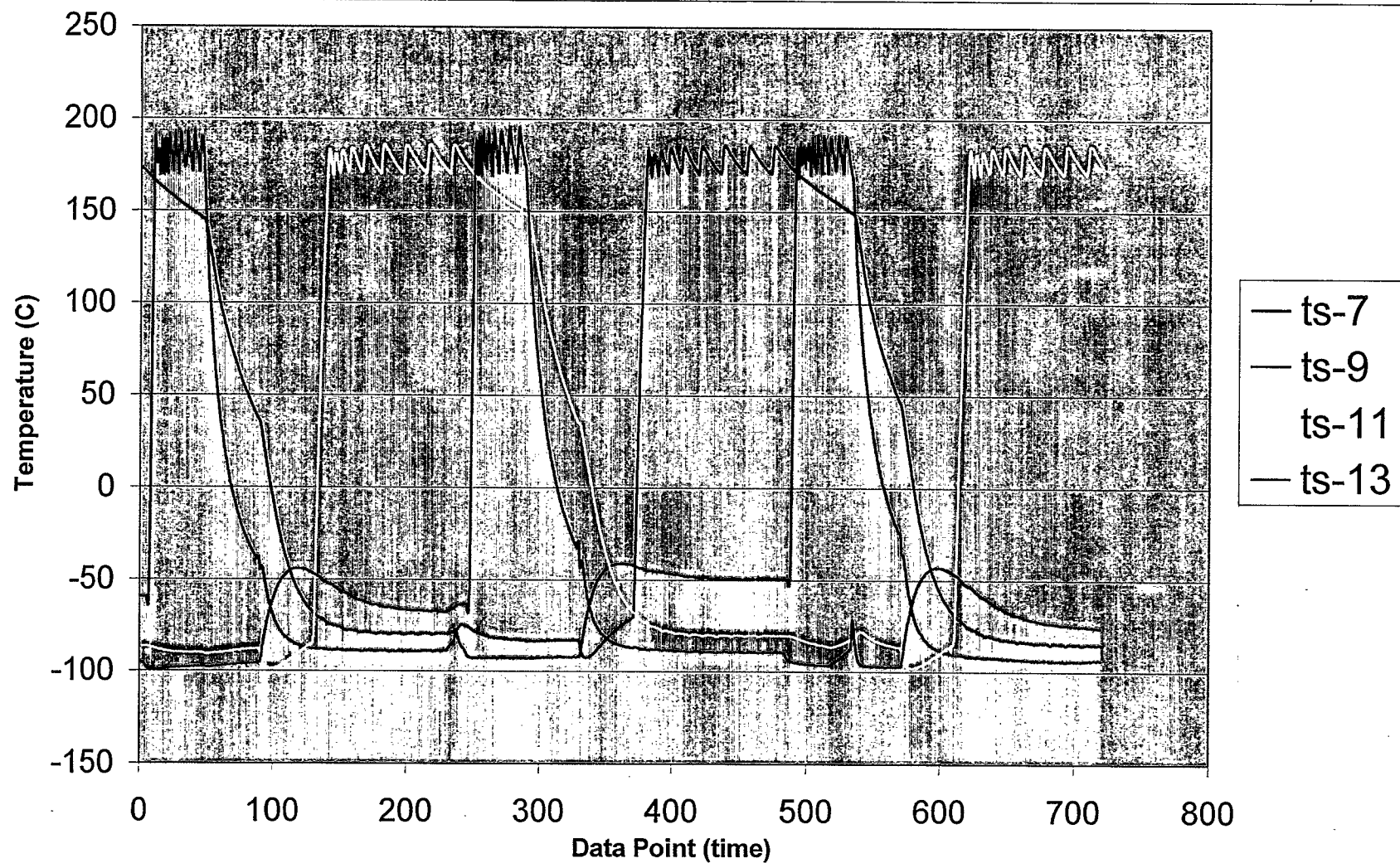


Figure 4. ARSA Pre-Trap and Main Trap Temperature Sensor Readings for a 24-hour SOH file