

An Investigation of Long-Term Stability of a Precision Platinum Resistance Thermometer up to 660°C

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Abstract

A new precision (secondary) platinum resistance thermometer with an upper temperature limit of 661°C and an inconel protection sheath was developed at Hart Scientific five years ago. In order to verify the long-term stability of these thermometers at high temperatures, a few were tested for stability at 665°C over 20,000 hours. The drifts of the thermometers' resistance at the triple point of water were as good as the equivalent of 0.002°C after the thermometers were exposed to 665°C for over 1000 hours. After long-term exposure to high temperature, the thermometers were calibrated to determine whether they still met the requirements of ITS-90. In this paper, the test results of some of these thermometers are presented. Some issues that may affect the stabilities of the thermometers are discussed. And the stabilities of some customers' thermometers returned for routine calibrations are also reported.

Introduction

Standard platinum resistance thermometers (SPRTs) are widely used as standard, or "reference," thermometers to calibrate other thermometers and to measure temperature precisely in primary and secondary laboratories. However, SPRTs are very fragile and expensive. For many secondary laboratories, industrial platinum resistance thermometers (IPRTs) have not been accurate or stable enough to meet the necessary requirements, yet SPRTs provide more than what is necessary and cost more than budgets allow.

Five years ago, Hart Scientific developed a precision platinum resistance thermometer (PRT) with an upper temperature limit of 661°C and an inconel protection sheath, based on a compromise between SPRTs and IPRTs.^[1] This PRT fills the gap between highly accurate but fragile SPRTs and rugged but less accurate IPRTs, based on a compromise of structure design. The structure of the thermometer is similar to that of an SPRT. The differences include the application of certain techniques to protect the element from contamination at high temperature and from mechanical shocks. It is important to find just the right material for the sensor. Not only does the sensor need protection from contamination and mechanical shock, it should also exhibit excellent performance in the

areas of thermal cycling and thermal hysteresis. The structure and design of the PRT were discussed and the test results were presented in an NCSL paper in 2000.^[1]

Since then, a few PRTs have been tested for stability at 665°C to verify their long-term stability. The exposure time at 665°C of several PRTs was over 20,000 hours. Over this period, their resistance values at the triple point of water and at the freezing point of aluminum were occasionally measured. After the long-term stability tests, for further verification of performances, these PRTs were calibrated in the range from -200°C to 661°C before and after 1000 hours exposure at 665°C.

In order to verify the performance of PRTs used by a variety of people and at a variety of locations, data from several PRTs sent in for routine calibration were collected and investigated.

Experimental Apparatus

A set of apparatus was selected for the investigation of long-term stability. The set included a few cells of the triple point of water (TPW) and their maintenance bath, a mini cell of the freezing point of aluminum (FP of Al), a mini fixed-point furnace, an electrical measurement instrument, a standard resistor, and a dry-well calibrator with an upper temperature limit of 670°C.

The triple point of water cells were maintained in a bath at about 0.004°C. The expanded uncertainty of the TPW was better than 0.1 mK. The stabilities of the PRTs were measured mainly at the TPW. In order to verify the stabilities of the PRTs at high temperature, the resistances of PRTs were measured occasionally in a mini FP of Al cell. The FP of Al was realized through a mini fixed-point furnace. Since the length of PRTs is shorter than that of typical SPRTs, PRTs usually cannot be measured through regular fixed-point calibration. The calibration uncertainties using mini fixed-point cells is much lower than when using comparison calibration. For reliability during the investigation, the mini fixed-point calibrations were chosen to verify the stabilities of PRTs at high temperature. This mini fixed-point cell and furnace were introduced in a previously published paper.^[2] The expanded uncertainty of the FP of Al realized in the mini fixed point furnace was better than 5 mK. A few PRTs were also calibrated in the Hart Scientific calibration laboratory using mini fixed-point cells and furnaces. The uncertainties of these calibrations were previously published.^[3]

A Hart Scientific Model 1590 “Super-Thermometer” was used as the electrical measurement instrument. Its measurement uncertainty for resistance ratios is 1 ppm. An external 100-ohm standard resistor was used as the reference resistance. The standard resistor was maintained in an oil bath at 25°C.

Testing and Results

Long-Term Stability at the Triple Point of Water

The long-term stability of the PRTs was mainly tested at the triple point of water after exposure at 665°C for around 20,000 hours. After a certain period of exposure at 665°C, the thermometer's R(TPW) was measured at the triple point of water. The R(TPW) drift for one 25-ohm PRT (S/N 0163) and one 100-ohm PRT (S/N 0446), as an example, are shown in Fig. 1 and Fig.2. The thermometer S/N 0163 was exposed at 665°C for 21,144 hours, and the thermometer S/N 0446 was soaked at 665°C for 17,556 hours.

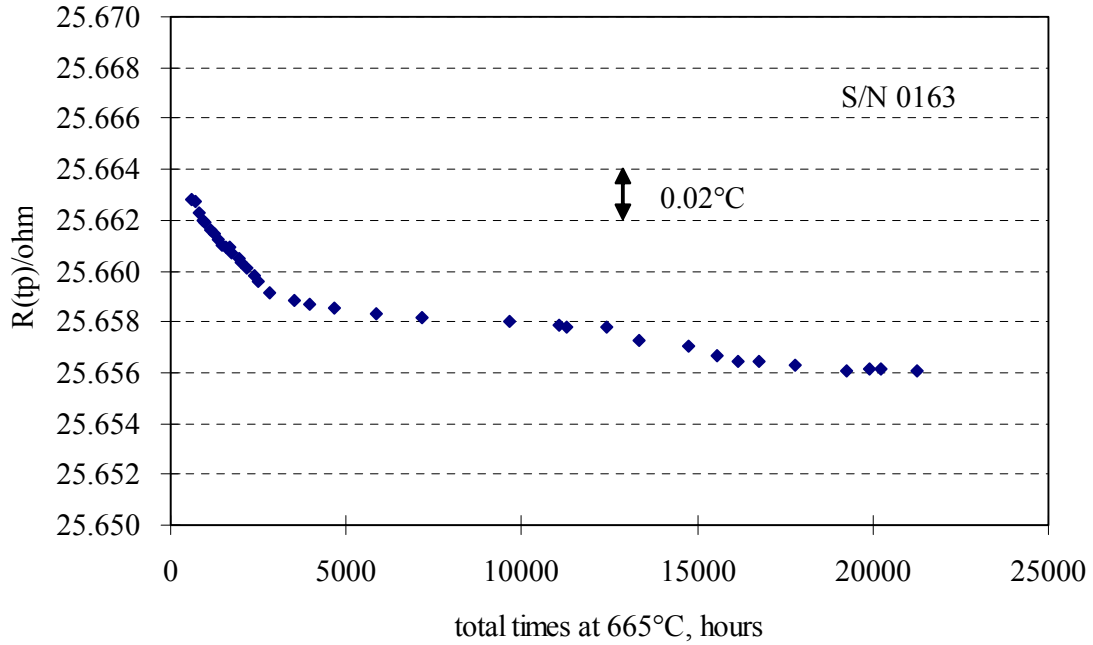


Fig. 1. Long-term stability for a 25-ohm PRT at the triple point of water

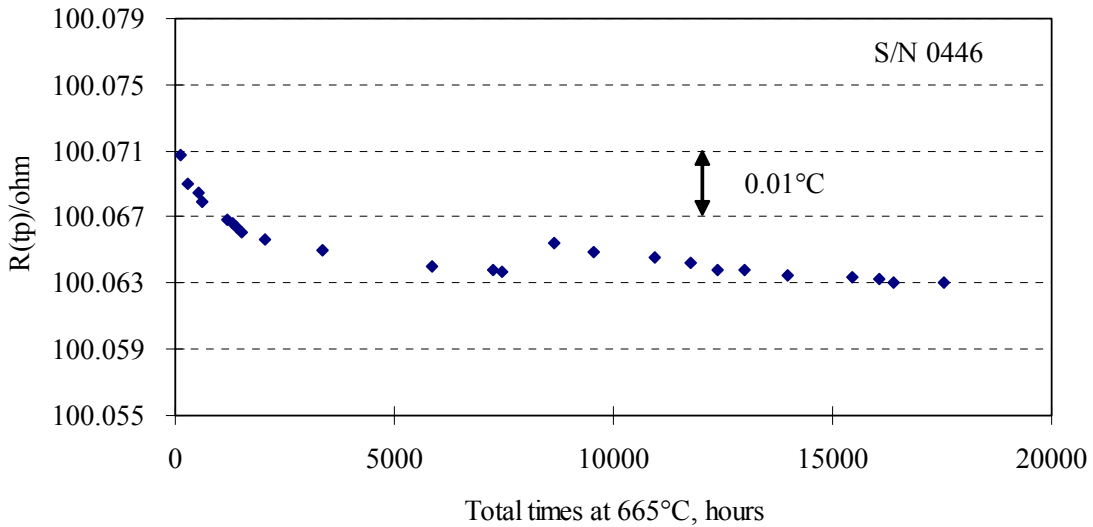


Fig. 2. Long-term stability for a 100-ohm PRT at the triple point of water

The R(TPW) of thermometer S/N 0163, a 25-ohm PRT, decreased quickly during the first 2,500 hours, then tended to be more stable. During the last 18,000 hours, the R(TPW) drift was less than the equivalent of 0.02°C. The fact that R(TPW) went down at the beginning means the strain on the element was gradually reduced. After the initial strain was eliminated, the thermometer was very stable for a long time; the R(TPW) drift was generally better than the equivalent of 0.002°C after the thermometer was exposed to 665°C for over 1,000 hours.

The 100-ohm PRT, thermometer S/N 0446, exhibited similar results. The difference was that the 100-ohm PRT stabilized more quickly than the 25-ohm PRT. R(TPW) of thermometer S/N 0446 fell very fast during the first 1,300 hours. After 1300 hours, the R(TPW) drift was around the equivalent of 0.01°C for a period of 16,000 hours. The reason the 100-ohm PRT became stable sooner than the 25-ohm PRT is that the element wire of the 100-ohm PRT was thinner and more flexible than that of the 25-ohm PRT. Since the test in our Primary Standards Laboratory was done very carefully, R(TPW) drift due to mechanical shock (abuse of the probe) can be ruled out. In practical use, it is likely that there will be some change in R(TPW) due to mechanical shock. The R(TPW) change due to mechanical shock of a 25-ohm PRT might be less than that of a 100-ohm PRT, since the 25-ohm PRT has thicker and sturdier wire.

Long-Term Stability at 660°C

To test the long-term stability of the PRTs at the upper limit of temperature, the PRTs were tested at the freezing point of aluminum after long-term exposure at 665°C. After a certain period of exposure at 665°C, the resistance R(TPW) of each thermometer was measured at the triple point of water first. Then the resistance R(Al) was measured at the freezing point of aluminum. R(TPW) was then measured once again. The resistance ratio W(Al) was calculated based on the formula $W(Al)=R(Al)/R(TPW)$. Using W(Al) to verify the stability will be more reliable than using R(Al).^[1]

W(Al) drifts for thermometer S/N 0163 and S/N 0446 are shown in Fig. 3. W(Al) went up very fast at the beginning, then tended to be stable, with a gradual rate of increase. For a total of 2,000 hours between 12,096 hours to 14,184 hours at 665°C, drifts of W(Al) of both thermometers were less than the equivalent of 0.005°C. The fact that W(Al) went up fast at the beginning means that the strain on the element was eliminated quickly. The fact that W(Al) went up slightly later indicated that the element was not being contaminated by the inconel protection sheath. Comparing the performances at high temperature, the stability of the 25-ohm PRT was better than that the 100-ohm PRT at the beginning. The W(Al) drift of thermometer S/N 0163 was less than the equivalent of 0.01°C, while that of thermometer S/N 0446 was less than the equivalent of 0.02°C. After the thermometers were fully stable, there was no significant difference between thermometer S/N 0163 and S/N 0446 with regard to performance at the freezing point of aluminum.

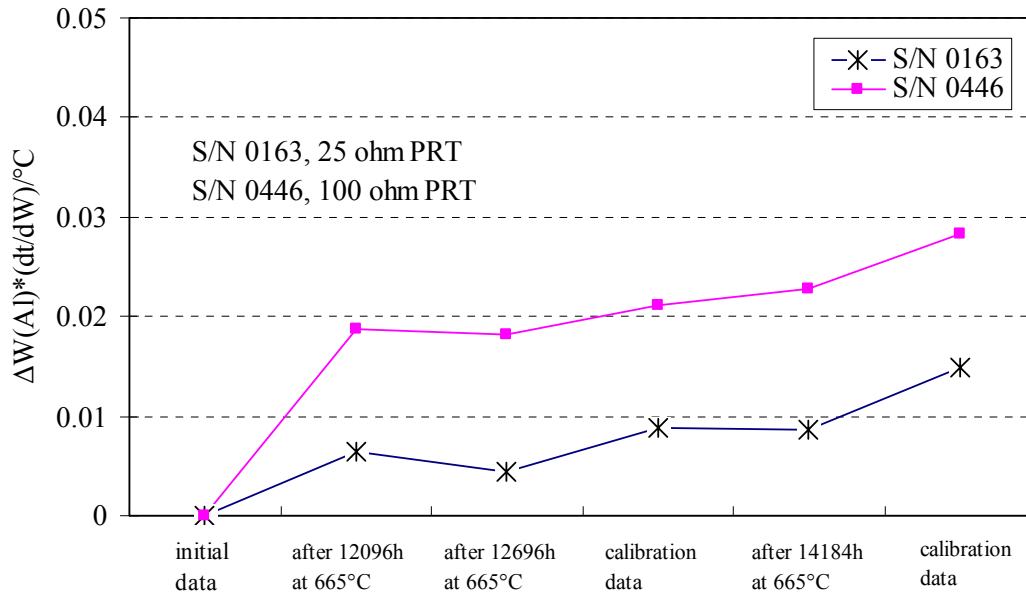


Fig. 3. Long-term stability at the freezing point of aluminum

Long-term Stability in the Range from 0°C to 661°C

In order to verify long-term performances in the range from 0°C to 661°C, two 25-ohm PRTs and two 100-ohm PRTs were calibrated at TPW, FP of Indium, FP of Tin, FP of Zinc, and FP Aluminum before and after 1,000 hours exposure at 665°C. All four PRTs were exposed at 665°C for over 15,000 hours before calibration. The test results are shown in Fig. 4, Fig. 5, Fig.6, Fig.7, and Fig.8. For all four thermometers, the maximum changes of R(TPW), W(In), and W(Sn) were less than 0.005°C, and the maximum changes of W(Zn) and W(Al) were less than 0.01°C and 0.015°C respectively.

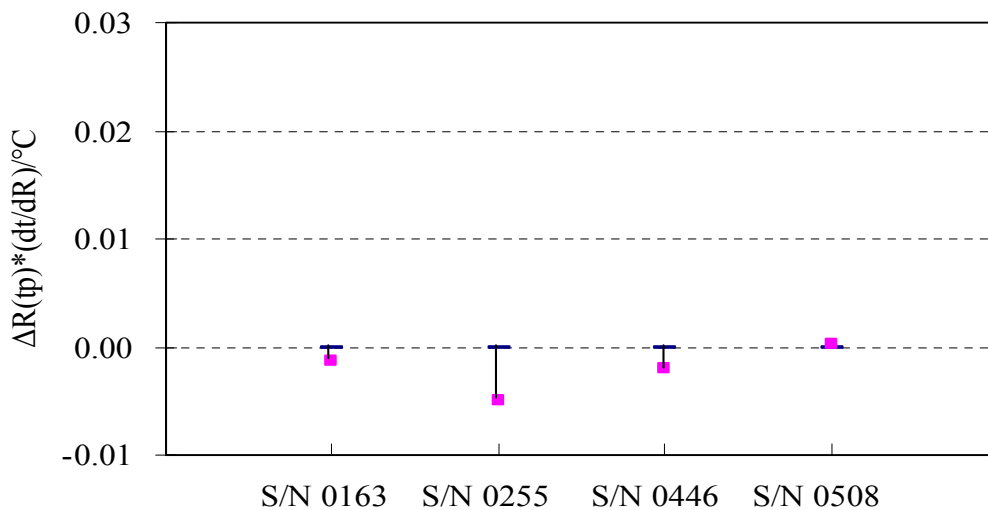


Fig. 4. R(TPW) changes before and after 1,000 hours exposure at 665°C

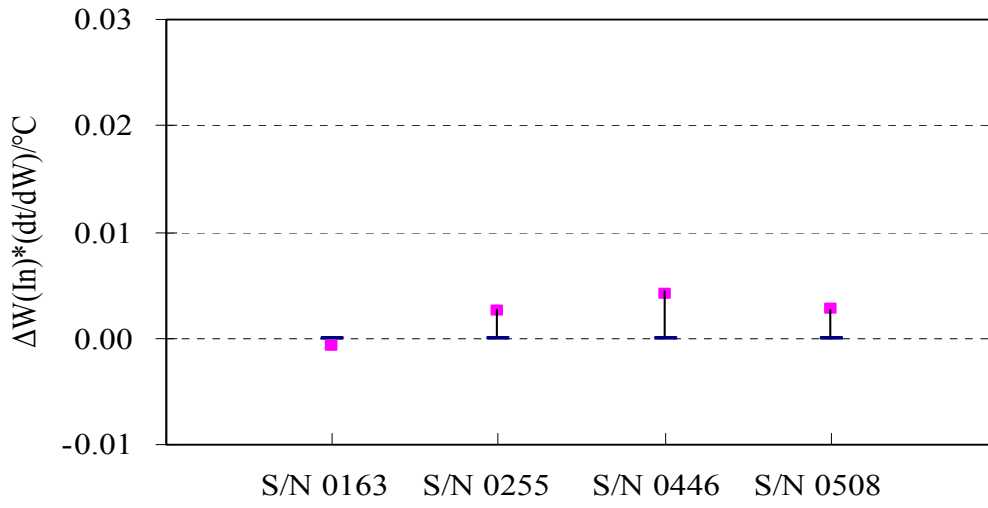


Fig. 5. W(In) changes before and after 1,000 hours exposure at 665°C

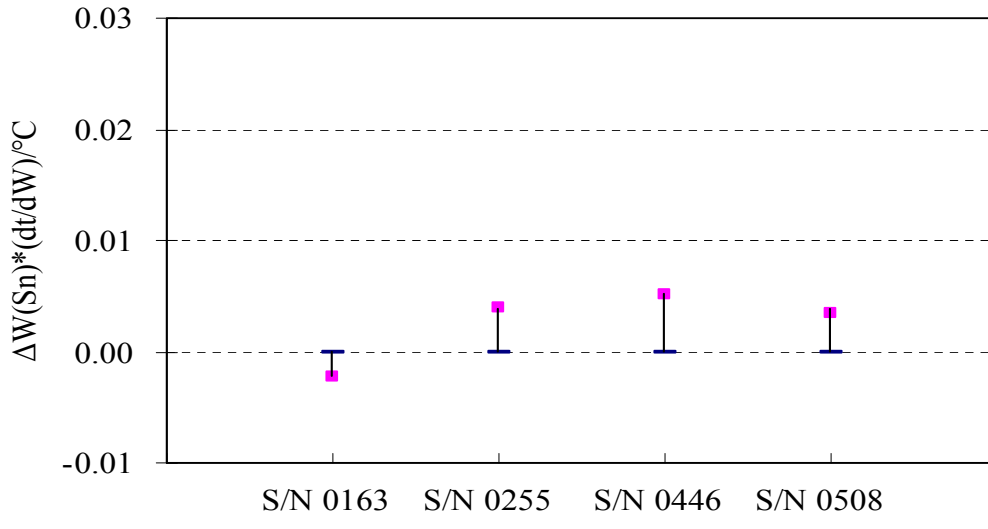


Fig. 6. W(Sn) changes before and after 1,000 hours exposure at 665°C

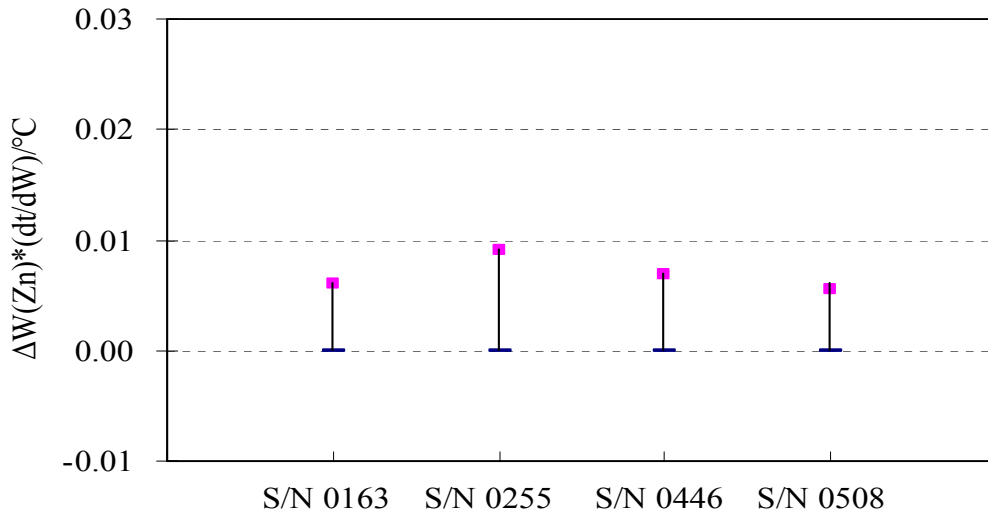


Fig. 7 W(Zn) changes before and after 1,000 hours exposure at 665°C

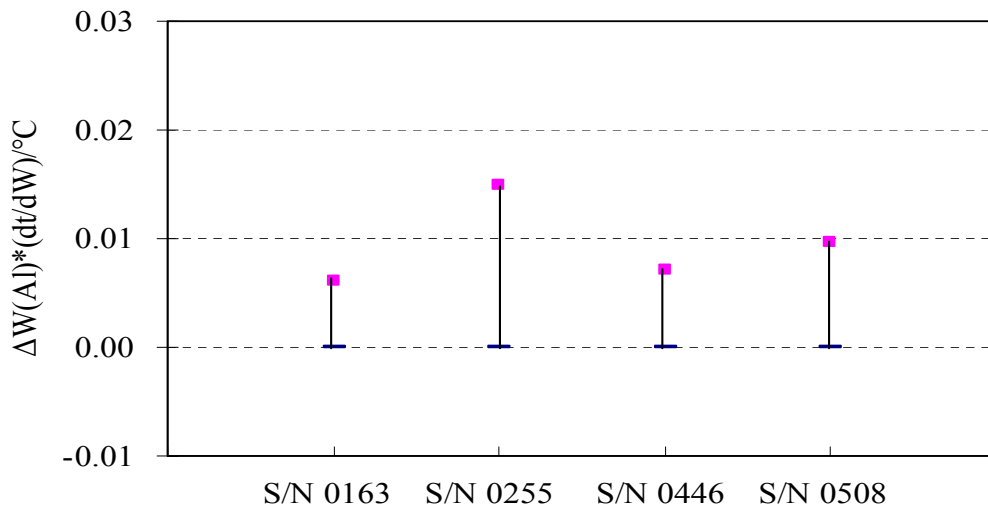


Fig. 8 W(Al) changes before and after 1,000 hours exposure at 665°C

Routine Calibration Investigation

As stated above, all these tests and calibrations were done carefully at the Hart Scientific primary standards and calibration laboratories. In order to verify the performance of PRTs used by various users at various locations, data for some PRTs sent in for routine calibration were also collected and investigated. As an example, the R(TPW) drifts of eight 100-ohm PRTs and eight 25-ohm PRTs over several years are shown in Fig. 9 and Fig. 10. The investigation results indicated that the annual R(TPW) drifts of the PRTs usually were less than 0.01°C. However, the R(TPW) drifts of PRTs were not identical among different users' thermometers. A few thermometers showed very good stabilities, while the R(TPW) of a few thermometers showed changes as large as 0.01°C every year, or even larger. The fact that the performances of all PRTs were very much the same in

Hart Scientific's laboratory indicates that the performance of PRTs depends partly on how the thermometers are treated.

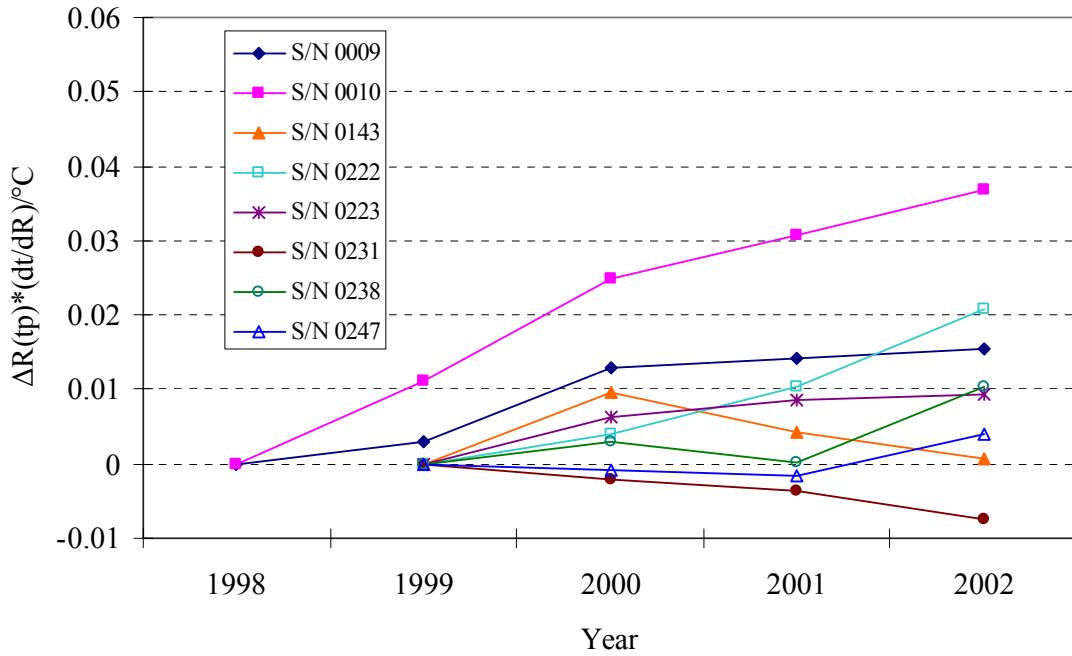


Fig. 9. R(TPW) changes over several years for 100-ohm PRTs used in the field

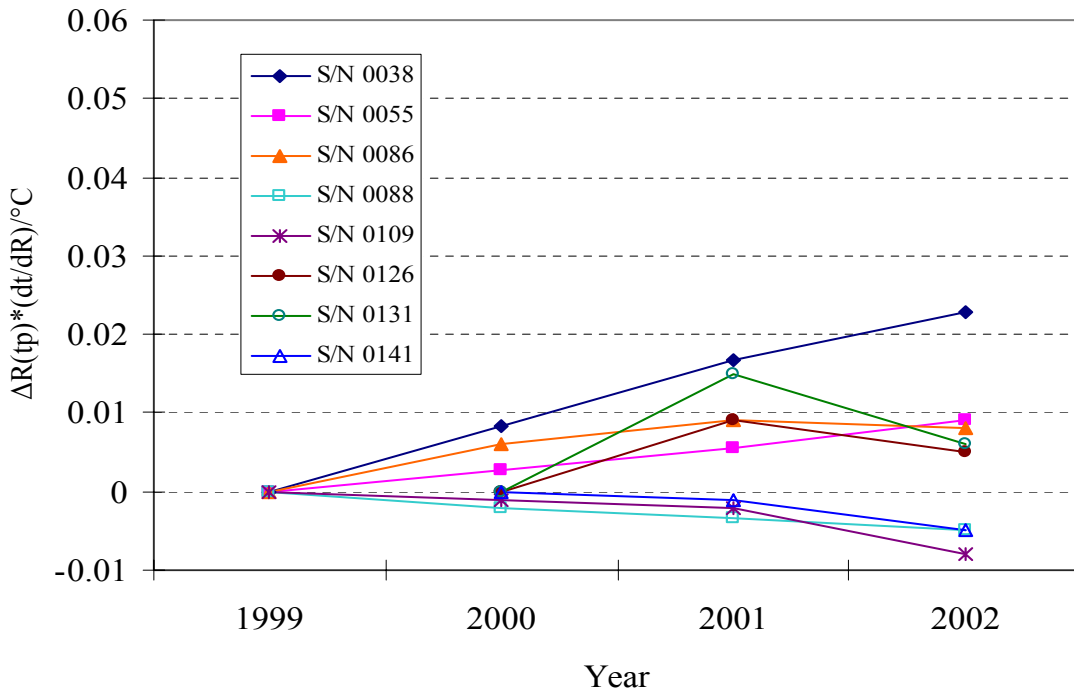


Fig. 10. R(TPW) changes over several years for 25-ohm PRTs used in the field

Conclusions

Long-term stability test results indicated that the R(TPW) of the thermometers went down very fast and W(AI) went up quickly early in the annealing process due to elimination of strain in the elements, and then tended to be stable. After the thermometers were fully stable, the R(TPW) drifts were usually better than the equivalent of 0.002°C after the thermometers were exposed to 665°C for over 1,000 hours. The R(TPW) drifts are less than the equivalent of 0.02°C for over 18,000 hours. The 100-ohm PRT stabilized faster than the 25-ohm PRT due to the increased thickness of the element wire. Routine calibration results showed that the thermometers were quite stable, but part of the performances of thermometers depended on how the users treated the probes. The investigation verified that the PRTs are an excellent secondary temperature standard for laboratories.

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