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IN-BORE MEASUREMENT OF 120-mm AMMUNITION TEMPERATURES

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ARMAMENT RDE CENTER

U.S. ARMY ARMAMENT RESEARCH, DEVELOPMENT AND
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14. ABSTRACT

This report describes the design, fabrication, and testing of an inert 120-mm tank ammunition cartridge, which, via wireless telemetry, transmitted data on gun tube/ammunition surface and internal temperature as the cartridge was placed into "battlecarry" after various quantities of rounds were fired. Battlecarry may be explained as the practice of chambering a round of ammunition with the tank fire control set for that type of ammunition so that the tank is ready to begin an immediate engagement. Three tests were conducted, one short and two longer series, and data indicated that for battlecarry following short series of ammunition fired, thermal input to the chambered round peaked shortly after loading, then stabilized. For battlecarry following longer series of ammunition fired, thermal input to the chambered round increased upon chambering, then continued to rise for the next 10 to 12 minutes until temperatures on the order of 150°F were achieved. The tests provided an illustration of the cumulative effect on gun tube heating of large quantities of rounds fired prior to battlecarry. Because of the mixing of several types of ammunition, differences in gun tube heating between several types of ammunition could not be determined. The test proved (continued)

15. SUBJECT TERMS
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the feasibility of telemetry temperature-measuring ammunition, which, due to their wireless configuration, may be used in the ammunition temperature measurement of other gun systems, from 40 mm up, and the lack of connecting wires could make this system particularly useful in the testing of autoloaded ammunition.

CONTENTS

FIGURES

FIGURES
(continued)

FIGURES
(continued)

INTRODUCTION/BACKGROUND

As part of a malfunction investigation on a particular variant of the 120-mm M865 Target Practice Cone Stabilized Discarding Sabot with Tracer (TPCSDS-T) ammunition (fig. 1), it was deemed desirable to investigate thermal input to 120-mm tank ammunition placed into battlecarry following the firing of several rounds of ammunition. FM 17-12-1, "Tank Gunnery (Abrams)", explains the concept of "battlecarry:"

> "*Battlecarry is a posture in which a tank is prepared for an engagement at all times, the main gun is loaded with a round of ammunition, the AMMUNITION SELECT switch or push button is set for the type of ammunition loaded...All engagements begin from this posture. This allows the crew to keep the fire control system prepared for an engagement at all times.*"

Battlecarry times may range from a few seconds to 10 min, or greater. The malfunction under investigation pertained to the deposition of up to quarter-sized chunks of epoxy (used to stiffen the projectile-to-cartridge joint) (fig. 2) upon firing, precluding subsequent ammunition from fully chambering. Early in the investigation, there existed data from training exercises that suggested that the cartridge battlecarried had a greater probability of depositing epoxy residue in the gun tube than those cartridges fired in a continuous sequence. It was theorized that at that time thermal input to the battlecarried cartridge (from a heated gun tube) was causing a change in the epoxy physical properties (or the cartridge case epoxy paint, or a combination of both), making the epoxy ring less likely to be broken up and expelled from the gun tube upon cartridge firing. As such, it was decided that the two areas of interest were the internal epoxy ring, and the surface of the combustible cartridge case and case adapter.

In order to quantify the degree of heating of a battlecarried cartridge, an inert cartridge with temperature sensors was designed and fabricated by the U.S. Army Armament Research, Development and Engineering Center (ARDEC), Picatinny Arsenal, New Jersey. Temperature data from the sensors was telemetered to a receiving station, and these data illustrated the degree of heating of several locations both on the surface of and within the epoxy bead itself. A telemetry (TM) design was chosen for its inherent self-contained nature; the cartridge could be handled and loaded as would any "live" round of ammunition without the encumbrances of wiring or cabling leading from the cartridge to data recorders. The cartridge internal configuration and temperature sensors would be transparent to the ammunition loader, a feature that was important to maintaining a rapid loading/firing cadence. Note: A later follow-on test of tactical ammunition (M830A1 HEAT-MP-T and M829A2 APFSDS-T) occurred several months later, and those results are discussed in a later section of this report.

TM TEST DESIGN

The interiors of gun tubes studied at the time of firing were previously measured. In 1995, the Army Research Laboratory conducted a gun tube wall temperature measurement ["Simulated and Experimental In-Wall Temperatures for 120-mm Ammunition" by P.J. Conroy, M.L. Bundy and J.L. Kennedy (Alliant Techsystems), June 1995], but these measurements (performed by installing thermocouples just below the surface of the gun tube) pertained to gun tube wall temperatures at the instant of firing. Additionally, they examined gun tube wall temperatures, and not how those temperatures affected ammunition carried in-bore. Since these temperature measurements (which ran for a maximum of 300 ms) were terminated before the time when the battlecarry round would normally be loaded (7 to 10 sec after the previous round was fired) and long before the battlecarried round as fired (this could be on the order of 10 min, or even greater), they do not provide information relevant to the investigation at hand. It would be necessary to conduct a new test to examine ammunition (and not just gun tube wall) temperatures several seconds after firing and continue monitoring those temperatures for a period of 10 to 15 min.

It was felt that the best means to capture the required ammunition temperature would be to fabricate a cartridge identical to the live M865 cartridge. The temperature-measuring unit could then be loaded in a rapid-fire sequence after several M865s were fired. Thus, design of an inert cartridge with temperature sensors would be undertaken, with the overall unit possessing the same physical properties as the M865 cartridge. Three means of capturing the temperature data were explored, all using the M865-like cartridge with temperature sensors located on and within specific areas of the cartridge. The first would use a data recorder located within the (inert) cartridge case of the temperature unit. The second would use hardwire to transfer temperature pickup data to a recorder located within the new crew compartment of the tank, and the third was a wireless TM system that would transmit temperature data to a recording station located nearby the tank. The on-board recorder concept was dismissed, as it would necessitate disassembly of the cartridge to extract the data. While not an insurmountable task, this would involve the additional step of unit breakdown, and it was desired to minimize the amount of on-site work of this nature. The hardwire recorder was dismissed as it would encumber the ammunition loader with a wiring harness, and it was not seen as making the temperature-measuring unit identical to the live M965s in terms of handling. Additional care would have to be exercised in order not to damage the wiring harness, and it was seen as a fairly difficult task to develop a wiring harness that would allow the temperature-measuring unit to be loaded into the ammunition ready rack. This drove the design to a TM-based unit.

Prior to the actual design and fabrication of the TM cartridges (two units were constructed), a test series was developed that would allow thermal input to a battlecarried cartridge to be measured. This test would replicate the actual training conditions pertaining to ammunition loading and firing cadence, but would be conducted at a test site. This would allow a controlled environment in which TM equipment (TM van, cabling, power supply, and antennas) could be placed without jeopardizing the equipment. It should be noted, however, that the inherent nature of the test setup (and the wireless TM cartridges) would allow the test to be conducted at a remote training site, although the tank would have to remain stationary in order that the TM signals were not out-of-range for the receiving antennas. Several M865 cartridges would be fired, in a rapid-fire sequence and then the TM unit would be loaded into the gun tube as if it were a following M865 cartridge. Because of its inert composition, it would not be fired, rather, it would remain in the heated gun tube for several minutes, transmitting temperature data to the receiving station. At the completion of the in-bore dwell, the TM unit would be extracted and the cartridge case and case adapter examined for any evidence (charring, blistering, or softening of the paint) of contact with an unusually hot surface (the gun tube itself). A second series would be conducted using a second, identical TM unit.

TM CARTRIDGE DESIGN

Prior to selection of the electronic component, it was necessary to measure the approximate gun tube temperatures, for the purposes of selecting an appropriate operating range for the temperature sensors. Proving ground testing with a hand-held pyrometer indicated that approximately 3 min after the last round was fired, gun tube wall temperatures were approximately 140°F after a 40-round group was fired. The 3-min delay was the approximate time required for personnel to mount the tank, open the gun breech, and insert the pyrometer. This left the rate of gun tube cooling from the 7 to 10 sec after firing (when the following cartridge would normally be chambered) to 3 min later (when the temperatures were actually measured) as an unknown.

While the hand-held pyrometer gave an indication of gun tube wall temperatures, it was thought that the use of temperature-indicating label strips might be a useful means to determine the cartridge surface temperatures themselves. These self-adhesive temperature sensitive strips (available from several manufacturers, but in this instance, manufactured by Omega International) were developed to provide a visual indication of the temperature of the surface to which they are applied. Once heated, they will retain a record of the highest reading achieved, and it was felt that they would provide the approximate temperature data being sought. Four sets of strips were applied with each set sensing temperatures in a specific range (with four of each label being used):

Omega catalog number TL-10-105-10 (105°F-180°F (40°C-82°C))
Omega catalog number TL-10-190-10 (190°F-280°F (88°C-138°C))
Omega catalog number TL-10-290-10 (290°F-380°F (143°C-193°C))
Omega catalog number TL-10-390-10 (390°F-500°F (199°C-260°C))

The labels were applied in a pattern similar to that which would be employed by the temperature sensors on the TM cartridge (figs. 3 and 4). Several M865 cartridges were fired, and the label-instrumented cartridge was rapidly loaded and allowed to remain in battlecarry for 5 min. Upon extraction, however, it was observed that none of the temperature labels indicated color change. It was felt that this was due to the labels being of insufficient thickness to bridge the clearances between the cartridge case and the gun tube. With no actual cartridge surface temperature data available, it was decided to defer to the pyrometer data and use 60°F as a lower limit for the TM cartridges with the upper temperature sensing temperature being 266°F (this based on capabilities of the temperature sensors selected).

In order to allow rapid extraction of the TM cartridge from the tank ammunition bustle rack and loading, it was necessary to simulate the physical properties (weight and center of gravity) of the M865 cartridge as closely as possible. Steel housing for the battery pack was fabricated based on the cartridge component physical properties so the weight of the battery cells, potting material, and other TM components would simulate the weight of propellant. This would yield a complete cartridge weight and center of gravity close to that of the actual M865 cartridge. Standard M865 projectile components (sabot and flight projectile, less tracer) were used, as were standard case adapters and case bases. The cartridge cases (combustible nitrocellulose-based material on the standard cartridge) were identical in terms of geometry to the actual component, but were constructed of an inert simulant. The lack of any energetic components was necessary to facilitate fabrication and test of the TM units without the safety concerns associated with energetic hardware. Both the case adapter and cartridge cases were painted with the same two-part epoxy paint system as was used on live ammunition. This would provide the additional data point of physical evidence of burning, melting, or discoloration of the cartridge case paint as a result of battlecarry in a heated gun tube. The area in the bottom of the cartridge case base (normally occupied by the ignition system primer) would be used as the location for a three-prong receptacle, the purpose of which would be to activate the TM unit and charge the internal battery. Nine temperature sensors located on and within the TM unit would provide temperature data. The TM cartridge would have a rechargeable battery with a life of approximately 1 hr. This meant that the time from switch on of the TM unit to placement into battlecarry could not exceed 45 min (allowing for 15 min of temperature measurement).

TM CARTRIDGE CONSTRUCTION

Specially fabricated inert cartridge cases were painted with the standard production epoxy paint process and furnished to ARDEC. Temperature sensors, capable of bridging the 0.030 to 0.060-in. cartridge case-to-gun tube clearances were designed, fabricated, and mounted to the cartridge case and case adapter. These sensors, in addition to being able to self-adjust to the slightly varying clearances of the cartridge in the gun tube, also had to withstand rapid extraction from the bustle rack and insertion into the gun tube. They were constructed of a strip copper-beryllium alloy ½-in. wide and approximately 2 in. in length (the contacts on the case adapter were shorter, being only 1 in. in length). They were formed with a large radius arch to them, and in the center of the arch was drilled a 1/16-in. hole. The hole allowed the tip of the temperature-measuring thermistor to protrude and contact the gun tube wall. The thermistor was held in place by potting within a ¼-in. length of 1/8-in. diameter tubing, soldered to the inside of the arch. The surface of the thermistor was covered by a small drop of epoxy (same material from which the stiffening ring was cast), this being done to provide a degree of abrasion resistance as the cartridge is chambered and dechambered. These six pickup assemblies were mounted to the cartridge case and case adapter with one end inserted into a slot cut in the cartridge case and case adapter; the assemblies were secured by countersunk screws (figs. 5 and 6). Nine temperature sensors were located on and within the TM unit. Sensors 1, 2, and 3 were located (respectively) 4 ½, 9 ¼, and 14 7/8 in. from the bottom of the cartridge case base. The ring of sensors 4, 5, and 6 was located 19 ¾ in. from the bottom of the case base (midway up the sides of the tapered cartridge case adapter), and the ring of sensors 7, 8, and 9 was at 21 3/8 in. In addition to the axial separation of sensors 1, 2, and 3, each sensor was rotated 120 deg from the previous sensor. Sensors 4, 5, and 6 were located and were 120 deg apart, as were 7, 8, and 9. In terms of their rotational placement, sensor 4 was rotated 60 deg from sensor 1 (between 1 and 2). The last three sensors (7, 8 and 9, the ones which would yield the most beneficial data) were embedded within the internal ring of epoxy at 120 deg intervals. In terms of their rotational alignment, sensor 9 was in line with sensor 1 (figs. 7 and 8). Sensors 1, 2, and 3 correspond to the straight-wall chamber section of the gun tube; 4, 5, and 6 correspond to the chamberrage section of the gun tube (just aft of the forcing cone); and 7, 8, and 9 represent internal cartridge components (epoxy ring).

Two M865 projectile assemblies (case adapter, sabot and flight projectile less tracer and stabilizing cone) were supplied to ARDEC; these were pulled from the ammunition production line and represented the configuration of ammunition “in the field,” which was depositing epoxy residue in gun tubes upon firing. Three blind holes 1/8-in. deep and 120 deg apart were drilled in the epoxy ring and temperature probes (sensors 7, 8 and 9) were potted in place (using the same epoxy for potting material as the ring was initially cast from). A longitudinal hole approximately 1/8-in. in diameter was drilled through one of the three sabot segments, parallel to and approximately 1 in. off the center-line of the flight projectile. This would allow insertion of the TM transmitting antenna (fig. 9).

The TM package was fabricated to mount to the inside of the cartridge case base, secured with countersunk screws. It consisted of an encapsulated rechargeable battery pack for powering the TM, a transmitter, and a 10-channel VCO board for transmitting nine channels of temperature data (plus one additional channel, which monitored battery voltage). Also, contained within the TM package was a TM control circuit and signal conditioning board for achieving a desired voltage span over a particular temperature range. These components were securely mounted to the inside of the steel cartridge case base. For external control (TM turn-on, turn-off, battery charge, and external voltage operation), three cambion jacks were installed in a modified brass primer housing, which was installed in the center of the case base (as would be an actual ignition system primer). The inert cartridge case was secured to the steel case base via a steel snap ring (the standard production method). Assembly of the components into the cartridge case yielded, basically, a cartridge consisting of two halves - one with the projectile and case adapter and the other with the case base and cartridge case. For access to the electronic components, the cartridge would not be permanently bonded to the case adapter (as in the case of tactical ammunition), but would be secured with 2-in. wide plastic tape. The tape would provide a joint of adequate stiffness (allowing normal handling and loading of the TM units) yet would allow disassembly of the TM units for maintenance or repair. A stainless steel hose clamp was installed in the sabot saddle area during the manufacture of the projectile. While this is normally removed prior to firing, it was left in place on the TM units to assure that separation of the sabot segments would not occur, impeding chambering, so as not to crush the TM antenna with the hose clamp; the clamp was threaded under the antenna. When completed, the TM cartridges weighed 30 lbs each and had a center of gravity approximately 11 in. from the bottom of the case base. The live M865 cartridges weigh 41 lbs each, and their center of gravity is located approximately 12.75 in. from the bottom of the case base. While the weight differential amounted to approximately 11 lbs (or nearly 25%), the center of gravity match between the two cartridges was relatively close, and in bench trials, ammunition handlers commented that the TM units "felt" very similar to the live cartridges. It appeared that a match between the live cartridge center of gravity and that of the TM unit contributed more to a feeling that the two cartridges felt the same than did a match of the weights. It was not, therefore, necessary to add the additional 11 lbs of weight to the TM cartridges solely to facilitate ergonomic similarity to the live cartridges. Figure 11 illustrates one of the completed TM units.

TM CARTRIDGE BENCH TESTS

Prior to cartridge readiness tests, each of the two systems went through a 5-point VCO calibration and 15-point signal conditioning board calibration (for each data channel). The final calibration check was conducted by placing sensors and then TMs in a temperature conditioning box, changing the temperature over the 20° to 130°C span (with 5°C step), transmitting data to the TM ground station, and comparing it to the readings of the control thermocouple. The data reduction was done using polynomial fit, graph polynomial fit, and temperature as resistance function equation. In other words, the known temperature of the conditioning box was verified by the TM unit. When the calibration was completed, the two TM cartridges were assembled and several bench tests were conducted at ARDEC to assess the units' readiness for field-testing (which occurred at Aberdeen Test Center). The first test investigated the functioning of the temperature sensors and their ability to adjust to the cartridge case-to-gun tube clearances. The first bench test consisted of placing an aluminum cartridge chamber gage (an aluminum cylinder machined to the same internal dimensions as a gun tube, used to gage test projectiles prior to shipment to a proving ground) in a high temperature conditioning box and soaking it for 120 min at 80°C. At the end of the hot conditioning, the conditioning box was opened, the TM unit was chambered in the aluminum tube, and response of the nine temperature sensors was noted. Temperature data was telemetered to a receiving antenna located outside the conditioning box, confirming that the temperature data was indeed being transmitted from the TM cartridge to the receiving antenna. This temperature data was compared to the temperature data of the control thermocouple placed on the inside surface of this aluminum tube; data correlation was good.

A second bench test was conducted, using the TM cartridge, receiving antennas and an M1A1 tank. The TM unit was activated and chambered in the tank gun with the breech closed. The TM signal strength was measured at various locations around the tank, and served as the basis for TM antenna positioning at the Aberdeen tests, which would follow. Once optimum TM receiving antenna location was established, the TM cartridge was dechambered from the gun. Although this was intended to confirm that the temperature sensors located on the surface of the cartridge case and case adapter would survive the rearward motion of the cartridge while being extracted from the gun, improper adjustment of the breech cartridge case deflector/ loading tray yielded flawed information. While the temperature sensors survived extraction from the gun at ARDEC, the loader's trays on fielded tanks are adjusted slightly differently (with respect to its height, compared to the rear face of the tube); it would later prove that testing at Aberdeen would damage the temperature sensors on cartridge dechambering. The free end of the temperature sensor hooked the loader's tray, bending the contact strip (fig. 12) and breaking the thermistor from the contact strip. This information was not available, unfortunately, until field-testing was underway, and required an impromptu repair to the contact and adjustment to the test procedure at the test site.

The TM unit identification numbers (a large TM1 and TM2 on each respective unit) were added to the bottom of the case bases. Also added to each case base bottom was a 12 o'clock index mark (fig. 13). This would ensure that the two cartridges were chambered with the temperature contacts in the same orientation. This information would be useful in data reduction later on as it would illustrate if the weight of the cartridge in the gun tube had any effect on the temperature contacts (contacts toward the bottom of the cartridge as it remained in battlecarry might have a greater footprint of contact due to the weight, and therefore, yield different temperature data from the contacts on top of the chambered cartridge).

TM CARTRIDGE TEST CONDUCT (TEST 1)

The Trench Warfare Range of Aberdeen Test Center was selected as the site for test conduct. An M1A1 tank was positioned on the firing pad; tube serial 6385 was installed. This tube had recently been returned from Fort Benning as part of the residue investigation and was at Aberdeen being used in residue generation tests. Its placement in the tank at the gun position dictated that it also be used for the TM tests (the TM tests were an add-on to residue testing on this gun tube). While generation of epoxy residue was an objective in the overall test (the overall test was to characterize the rate of epoxy residue deposition in this particular tube), it would prove to be a detriment as this would cause a delay in testing as residue was removed from one of the test series.

The tank, the TM receiving antennas, and the ARCEC TM van were positioned at the firing pad with two antennas abeam of the muzzle and approximately 50 ft off the line of fire (LOF) and the TM van (approximately) 100 ft behind the muzzle and off LOF of the tank. A third receiving antenna was located atop the van and the use of three antennas constituted a redundant feature of the test. As a final check, one TM cartridge (TM unit 2, this was random selection) was trial loaded into the tank gun to re-verify signal strength with the breech closed (which would be the actual test conditions). The signal strength was excellent; however, the design of the temperature sensors was such that two became damaged upon extraction from the gun tube. While the TM round was repaired, it was decided that the TM cartridges would be placed on and loaded from, the commander's seat (rather than being loaded into the ammunition rack, risking further damage to the sensors on extraction from the bustle rack). Production M865 cartridges of lot ORI00H703-002A, conditioned to 0°C, were available for test.

The test consisted of two of the following test series:

- Perform final checks on weapon system/firing position
- Load four each M865 cartridges into tank ammunition bustle rack
- Perform final checks/battery charge on one TM round and upload unit into tank.
- Load and fire four each M865 cartridges at (approximately) 7 sec intervals
- With no break in cadence, load TM cartridge and close breech
- Allow TM round to remain in tube for 15 min while temperature data is transmitted to receiving station
- Extract TM unit and prepare for second test sequence

Since tube 6385 was only recently installed in the tank, Aberdeen Proving Ground safety procedures dictated that three each M865 cartridges be remotely (no personnel in the tank) proof fired. These rounds were fired at 10:37, 10:41, and 10:43 hrs with no anomalies, after which time four each M865 rounds were uploaded into the tank ammunition bustle rack, and TM cartridge 1 (TM1) was activated and placed on the commander's seat. The first sequence began with M865 rounds being fired at 10:54:21, 10:54:32, and 10:54:44. Loading of the fourth M865 was not completed as a chunk of residue precluded the round from fully chambering (it stuck approximately 2 in. out of the rear of the tube). Residue took the form of a quarter-sized chunk of epoxy, with case adapter bonded to the backside, and was bagged for return to ARDEC.

Following extraction of the stuck round, four additional M865 cartridges were uploaded, and testing resumed. M865 rounds were fired at 11:19:29, 11:19:40, 11:19:49, 11:20:00, and TM1 was loaded at 11:20:13. It was extracted after approximately 17 min in-bore.

Four more M865 rounds were uploaded and telemetry unit 2 (TM2) was activated and placed on the commander's seat for use. M865 rounds were fired at 11:53:54, 11:54:05, 11:54:16, 11:54:28, and TM2 was loaded at 11:54:39. Although TM2 was left in the gun tube until personnel returned from break (more than an hour had elapsed), the battery fully discharged approximately 37 min. A full tabulation of test times is shown in figure 14; included are time of chambering (TOC), time of firing (TOF), time in chamber (TIC) and time between firings (TBF). For purposes of simplicity, only TOF was discussed previously in this text. In the case of the chambering of a TM round, TBF for that round (which was not fired) is the time between the firing of the previous live round and the breech closing of the TM round insertion.

RESULTS (TEST 1)

Since there were multiple insertions of the TM units in test 1 (two insertions), an identification nomenclature was developed to indicate the test number and the insertion number. Thus, "1-1" indicates the first insertion of a TM unit in test 1, "1-2" the second insertion in test 1. Since both units performed identically in bench tests, no differentiation between TM unit 1 and 2 is made in the following discussion, although that information is noted on the data sheets.

Reduction of the raw "as-taken" data (which took the form of voltage versus time drop for each temperature sensor) yielded plots of temperature versus time for each of the nine temperature sensors on each TM cartridge. Data analysis and display (DADISP) digital software, which converted the as-received voltage versus time data to temperature versus time, performed this data reduction. Figures 15 through 17 illustrate the time/temperature curves for TM unit 1. Note that the data was reduced to Fahrenheit units (rather than the perhaps more common Celsius units) so as to provide a correlation to the gun tube pyrometer data taken earlier. It was felt to be of little importance to present the raw voltage versus time curves since they are, expectedly, identical to the voltage versus time plots derived from the conversion software.

In the interest of efficient data presentation, it was noted that there were nine individual sensors (three groups of three at three different locations) that produced time versus temperature plots. Examination of the data indicated that sensors 4, 5, and 6 yielded nearly identical plots (to each other), as did sensors 7, 8, and 9. There were slight differences, however, between sensors 1, 2, and 3 (discussed later). Thus, the data (for each insertion) will be presented as a single plot with five curves:

Sensor 1
Sensor 2
Sensor 3
Average of sensors 4, 5, 6
Average of sensors 7, 8, 9

This abbreviated data presentation format (which will be used for all insertions) is shown for insertion 1-1 in figure 18 and 1-2 in figure 19.

The surface of the case adapter (sensors 4, 5, and 6) shows the greatest temperature rise, achieving approximately 82.5°F in insertion 1-1 and 86°F in 1-2. The time to those temperatures was on the order of 60 sec for both insertions. The surface of the cartridge case (sensors 4, 5, and 6) remains slightly cooler, and the temperature of the internal ring of epoxy (located within the cartridge case adapter) reach temperatures similar to that of the surface of the case adapter (78°F in 1-1 and 79°F in 1-2), but requires a longer time in which to do so (13 min in 1-1 and 15 min in 1-2).

It is noted, perhaps unexpectedly, that the internal epoxy ring reached the same temperature as did the surface of the cartridge, indicating that the cartridge case adapter and nylon insert provided quite efficient thermal conductivity. All of the data observations discussed hold true for both insertions, although the recorded temperatures of insertion 1-2 were slightly higher across-the-board than were those of insertion 1-1. This was perhaps due to the fact that by the time TM unit 2 was chambered, a total of 14 rounds were fired, as compared to only 10 being fired before TM 1 was chambered. This might indicate that the maximum gun tube temperatures are influenced not only by a group of rapidly fired ammunition, but rather by the total number of rounds fired in one given occasion. It appears that even after firing has ceased (or is broken by long delays), the gun tube still retains some degree of heat. This would be confirmed in later tests.

An additional observation was made concerning the actual loading times of the TM units. When damage to the temperature pickup was realized on dechambering the TM unit from the gun (prior to actual test conduct) and it was decided that the TM units would be stored on the commander's seat, there existed concern that once the loader had reached a set cadence extracting ammunition from the turret storage rack and chambering, the change in location of the TM unit would adversely affect loading times. While removal of the TM units from the commander's seat was distinctly different from the loader's usual motion of extracting the cartridge from the ammunition storage rack and chambering it, it was noted that the placement of the TM units on the commander's seat did not appreciably alter loading time (as compared to the firing cadence of the live rounds loaded from the bustle rack). It was also noted that while the live ammunition was chambered without regard to clock orientation, the additional instant required for the ammunition loader to ensure that the 12 o'clock marks on the TM cartridges were indeed up (and rotate the cartridge in the loader's tray if it was not) had little, if any effect on the chambering time, allaying fears that this additional step would adversely affect TM unit loading times. The break in cadence between the firing of the last live round and the loading of the TM cartridge never materialized.

A table of temperatures appears at figure 21. It briefly summarizes the quantity of rounds fired prior to, and the duration of time each TM unit is placed in-bore. This table contains data from test 1 as well as tests 2 and 3, conducted at a later date.

POST-TEST DIAGNOSTICS (TEST 1)

There were slight anomalies in the cartridge case surface temperature data on both insertions (sensors 1 to 3), namely that three different maximum temperatures were achieved. Since the three sensors were staggered in both axial location and clock position, it was uncertain at the time of testing whether the recorded temperature differences were due to axial or clock position. It is noted that in the case of both TM cartridges, the sensor at the 12 o'clock position (sensor 1) recorded the lowest temperature, followed by the 4 o'clock sensor (sensor 2), then the 8 o'clock sensor (sensor 3). Since the cartridge case base and the projectile front bourrelet (bore riding surface) center the cartridge within the gun, it was not envisioned that the lower contact would be forced into more intimate contact with the gun tube than would the upper sensors, although logic dictates that IF this was taking place, the temperature readings would have been exactly as what were observed.

After the test was concluded, an investigation into the apparently anomalous curves between sensor 1 and sensors 2 and 3 was conducted. Initially discounted was the theory that the upper temperature sensor showed a lower temperature reading because it was not making the same contact as the lower two sensors (due to gravity affecting the sit of the chambered cartridge, pulling the upper contact away from the gun tube wall. Instead, it was believed that the differences in temperature readings were not due to the rotational orientation of the three sensors, but due to their axial (down bore) location. The sensor, which indicated a slightly lower temperature (sensor 1), was located closest to the large steel mass of the battery housing and the cartridge case base. Since the case base is in intimate contact with the gun tube, and the battery housing is attached to the case base by steel screws, this entire assembly may be thought of as a large heat sink. The theory that the case base/battery housing was drawing heat from the aft end of the cartridge was investigated by performing an additional bench test of the cartridge. TM 2 (this was a random choice) was used for this test; it was not felt necessary to perform this test on both TM units as they both showed the same data concerning the temperature curves for these same three sensors.

For this test, TM 2 was modified by the removal of the case base. The battery housing and circuit board assembly were secured directly to the bottom of the cartridge case, eliminating the steel case base. This effectively insulated the steel battery pack from contact with the heated gun tube simulant, and also eliminated the rear centering feature of the cartridge (the rear of the cartridge, without the case base, would tend to fall toward the bottom of the gun tube more so that if the case base were present). In this test, the chamber gage (which would simulate the heated gun tube) was again heated to 176°F, and upon removal from the conditioning box, the cartridge was inserted into the gage in the horizontal orientation, simulating chambering in the vehicle weapon. Sensor 1 was oriented at the 12 o'clock position, and in this test, it again showed a slightly different temperature than did sensors 2 and 3. After 2 ½ min in the gun tube simulant, the entire test assembly (the TM cartridge within the heated chamber gage) was rotated 180 deg so that sensor 1 was now at the 6 o'clock position. An immediate change in temperature response was noted. After an additional 6-½ min, the assembly was rotated back to its original orientation (sensor 1 at 12 o'clock); changes in the temperature response of the three sensors were again noted. Figure 20 shows the temperature curves for sensors 1, 2, and 3 and clearly indicates where, during the test, the test fixture was rotated 180 deg. This indicates that, despite the self-adjusting nature of the temperature sensors, when a sensor is at the bottom of the gun tube (as opposed to the top), a slightly different contact with the gun tube was present.

TM CARTRIDGE TEST CONDUCT (TEST 2 AND 3)

Several months after test 1 was completed, and additional investigation was convened, this one examining the temperatures of a 120-mm gun tube and tactical ammunition placed into battlecarry (test 1 concerned itself only with training ammunition). Investigated in these tests were 120-mm HEAT-MP-T M830A1 (a shaped charge, high-explosive, multipurpose cartridge), APFSDS-T M829A2 (a depleted Uranium discarding sabot armor penetration cartridge), and for reference, the M865 training cartridge. Figures 22 and 23 illustrate the general configurations of the M830A1 and M829A2 cartridges, respectively. The amount of ammunition fired dictated that the test be conducted over two days; ammunition fired on the first day was designated "Test 2" and that which was fired on the second day designated "Test 3" (with the earlier test conducted in March being designated "Test 1"). This was because cooling of the gun tube overnight, and the commencement of firing the following morning from a cold tube essentially constituted a new test.

Prior to test conduct, refurbishment was performed on both TM units. This included a checkout of the TM system, batteries, and antenna. The temperature sensors were also redesigned, based on their failure upon extraction from the gun tube or ammunition ready rack in test 1. The redesign entailed capturing the free end of the temperature sensor spring so that rearward motion of the contact over an uneven surface (such as from the breech into the gun tube) would not cause the contact's free end to hook on the surface irregularity. This improvement was made to all of the external sensors (sensors 1 through 6); sensors 7 to 9 were left unmodified as their internal location protected them during cartridge chambering and dechambering. The configuration of the improved temperature sensors is shown in figure 24.

The conduct of test 2 and 3 would be essentially identical to the M865 test (test 1) conducted earlier: several rounds (groups of similar types of ammunition) would be fired, then the TM unit chambered to record ammunition and gun tube temperatures for some length of time after the chambering. The same gun tube as used in the first M865 tests was used; however, by this time, the tube and reached its fatigue life (determined by number of rounds fired) and its subsequent declaration as a "condemned" tube necessitated that it be fired remotely from the hardstand mount (as opposed to the first test that was conducted from a tank).

The following test matrix was used for this series:

Fire 8 each M865 cartridges
Fire 15 each M829A2 cartridges
Fire 15 each M830A1 cartridges
Fire 8 each M865 cartridges
Fire 15 each M829A2 cartridges
Fire 15 each M830A1 cartridges
Fire 8 each M865 cartridges
Fire 15 each M829A2 cartridges
Fire 15 each M830A1 cartridges
Fire 8 each M865 cartridges

Ammunition from the following lots was used:

M865	0RI00G123H002	40 each
M829A2	MHM96K824-002	60 each
M830A1	MHM94B130-005	26 each
	MHM94C132H001	6 each
	ORI99F131-001	28 each

Whereas the ammunition fired in test 1 was chambered and fired as rapidly as possible, test 2 and 3 used a staggered firing cadence. Within each group of ammunition, the following firing sequence was used:

Chamber one round
Immediately fire
Immediately chamber
Wait 2 min
Fire
Immediately chamber
Immediately fire
Repeat the sequence

In other words, ammunition was fired with an alternating "fire immediately upon chambering" and "fire 2 min after chambering" cadence.

Test conduct proceeded as per plan, with several instances of the cadence being broken by residue generated by firing the M865 ammunition. In two of these instances, chambering of the TM unit was not possible until the residue was removed, and in these cases, the TM unit was not chambered. The test proceeded with the next group of ammunition. Since the ammunition was loaded into a gun mounted on a hardstand, the ammunition had to be physically located behind a barricade. This meant that the time between a round being fired and the TM unit being chambered was slightly greater than in test 1, where the TM units were more readily accessible to the ammunition loader. During test 2 (the first day of firing), TM units were left in-bore for 5 min. At the completion of the day's testing, a quick look at the data was performed, and it was noticed that at the end of the 5 min in-bore period, the temperature of several of the sensors was still on the increase. Based on this, TM in-bore time was increased to 10 min in test 3, with the last occasion of TM unit insertion being for longer than 30 min duration (although the temperatures had stabilized after 10 min). A detailed spreadsheet of firing time, types of ammunition fired, and TM unit insertions appear in figure 25.

RESULTS (TESTS 2 AND 3)

Test results were essentially identical to test 1 in terms of the general shape of the time/temperature plots for the nine temperature sensors. Examination of the nine temperature curves (in groups of three) revealed the same trend as was seen in test 1, namely, that sensors 1, 2, and 3 showed a slight difference (between themselves), but that sensors 4, 5, and 6 and 7, 8, and 9 showed good correlation. Time versus temperature plots were, therefore, shown in the same five-curve format as for test 1:

Sensor 1
Sensor 2
Sensor 3
Average of sensors 4, 5, 6
Average of sensors 7, 8, 9

Tests 2 and 3 offered a glimpse of ammunition in-bore temperatures (ammunition in battlecarry) after much higher quantities of ammunition was fired over that in test 1. For the purposes of simplicity, one particular curve will be discussed, that being the maximum temperature achieved, the average of sensors 4, 5, and 6. To normalize the curves, a one time interval was chosen that would be encompassed by all of the TM insertions (which varied between tests), that being at 4 and 5 min after the TM round was chambered. There was a noticeable difference in the shape of the temperature versus time curves as higher quantities of rounds were fired. For the smaller quantities of rounds fired, temperature tended to increase to a maximum, then remain relatively constant whereas for higher round counts (greater than 20 to 25), the temperature at this point (and at this time, 4 min) continued to increase. For some of the much higher round counts, the temperature was still increasing after the TM unit had been chambered for the requisite 4 min (peaking after 10 to 12 min). This was due to heating of the chambered TM unit being performed by the large mass of the gun tube. As more and more rounds were fired, the gun tube wall had been heated to higher and higher temperatures and was capable, therefore of returning greater and greater amounts of thermal energy to the chambered TM unit. This heating of the in-bore TM unit was not possible when small quantities of ammunition had been fired. Figures 26 through 41 illustrate the time/temperature profile for tests 2 and 3 after varying quantities of ammunition were fired, as well as a summary of temperatures for a given sensor (average of sensor 4, 5, and 6) over several tests. Figures 33 and 41 illustrate (for test 2 and 3, respectively) the peak gun tube wall temperature (average of sensors 4, 5, and 6) as a function of cumulative rounds fired. The slight drops in the curve are due to variances in the time between the firing of the last round and the insertion of the TM cartridge.

An interesting question, which unfortunately, could not be answered because of the staggered quantities/types of ammunition fired would have been "was there a noticeable difference in gun tube heating with different types of ammunition (and, therefore, different propulsion systems)?" Since the TM units were chambered after eight trainer M865s and 15 tactical M829A2s were fired (each of these two groups starting with a cold gun tube, so as not to encounter the effects of cumulative tube heating), the cumulative effect of gun tube heating differed at the end of each test sequence (after 8 rounds versus after 15 rounds). Therefore, it was not possible to ascertain from the TM data if the tactical ammunition heated the gun tube at a higher rate than did the training ammunition.

CONCLUSIONS

These tests illustrated the thermal input to a gun tube as a result of three groups of up to 76 rounds being fired in a relatively rapid succession (actually, test 2 consumed 84 rounds, but residue deposition in the gun tube precluded the last TM insertion from being carried out). Therefore, test 2's last TM unit insertion was after 76 rounds were fired. Quite expectedly, the gun tube heating was a function of the cumulative round count fired on a given occasion (heating increased as more ammunition was fired). Since the temperature measurement of the gun tube was a secondary objective (residue collection from both tactical and training ammunition being the primary), the test was fired in alternating groups of similar type ammunition. Had temperature profile been the primary objective, it perhaps would have been better if the test, centered around three distinct types of ammunition, was fired over three days, each day being dedicated to one type of ammunition. Since this was not done, it was not possible to determine if gun tube thermal input was different with each type of ammunition because only two types of ammunition was fired beginning with a cold gun tube (where thermal input from the previous group of ammunition was not an influence). Nevertheless, examining the data not by specific type of ammunition, but as one homogenous group of 120-mm ammunition indicates that the gun tube reaches temperatures on the order of 145°F. Examination of the one insertion that was extended past 30 min (insertion 3-6) illustrates that this temperature remains constant for a long period of time after firing has ceased (notice that this insertion is presented in the figures as truncated to 10 min to keep it in the same format as the other insertions). A much more gross and general illustration of this was witnessed at the test site, where, as long as 90 min after firing was terminated, the thermal shroud of the gun tube (and not the gun tube itself) was hot to the touch.

A final comment is in order concerning the TM setup used in these experiments, that being that the self-contained nature of the TM cartridges makes them (or, rather, the operational concept of them) readily-adaptable to ammunition of varying calibers. Some interest has been expressed in using this technology to determine the temperature of an artillery propelling charge loaded into a hot gun tube. It is felt that with minimal downsizing, this temperature-measuring concept is adaptable to ammunition as small as 40 mm and, of course, to calibers greater than the 120 mm studied herein. Since there is no "hard wire" connection from the temperature sensors to the temperature recording equipment, this concept is also readily adaptable to autoloaded ammunition. The lack of wiring proved extremely beneficial in maintaining a specified firing cadence and is seen as a large benefit in the case of rapid fire, autoloaded ammunition, such as the type being developed for the Future Combat System and the Brigade Combat Team.

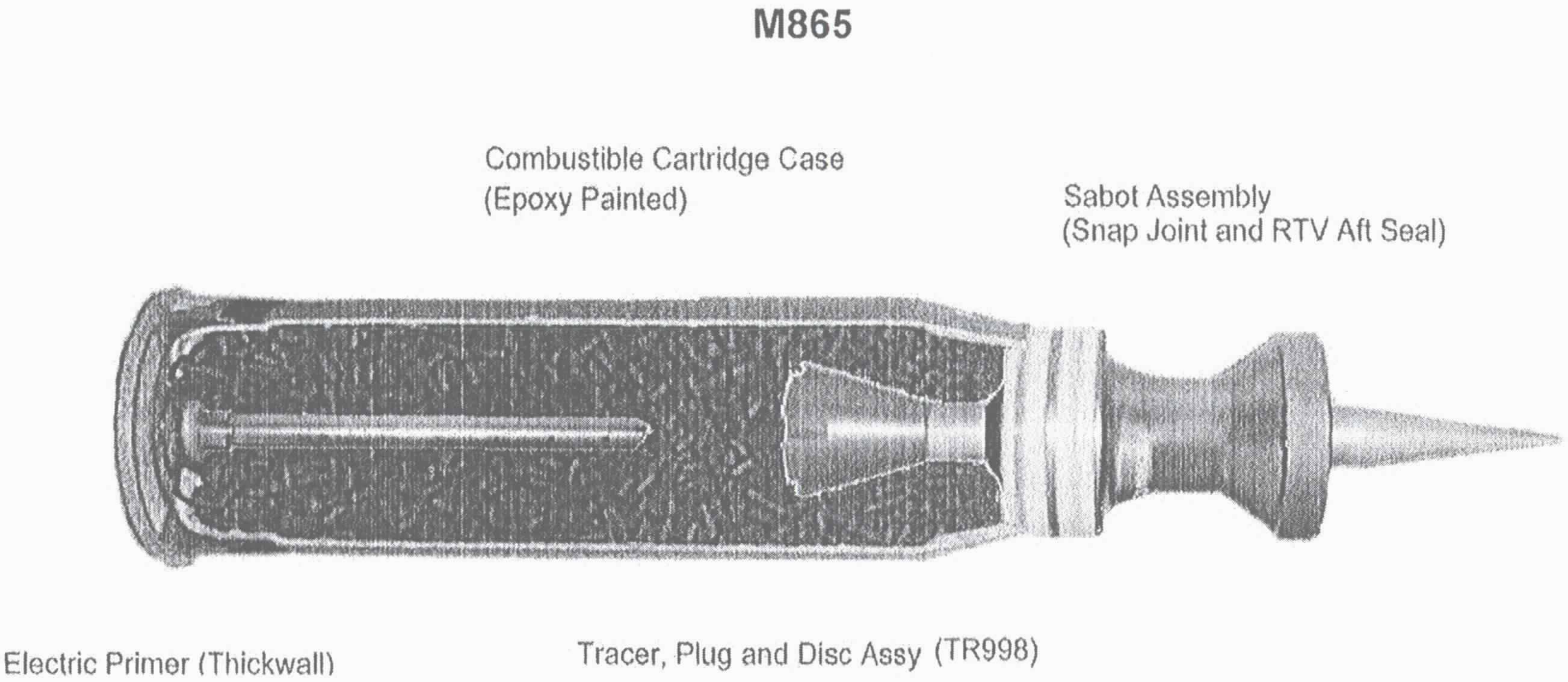

Figure 1
Target practice cone stabilized discarding sabot with tracer (TPCSDS-T) M865

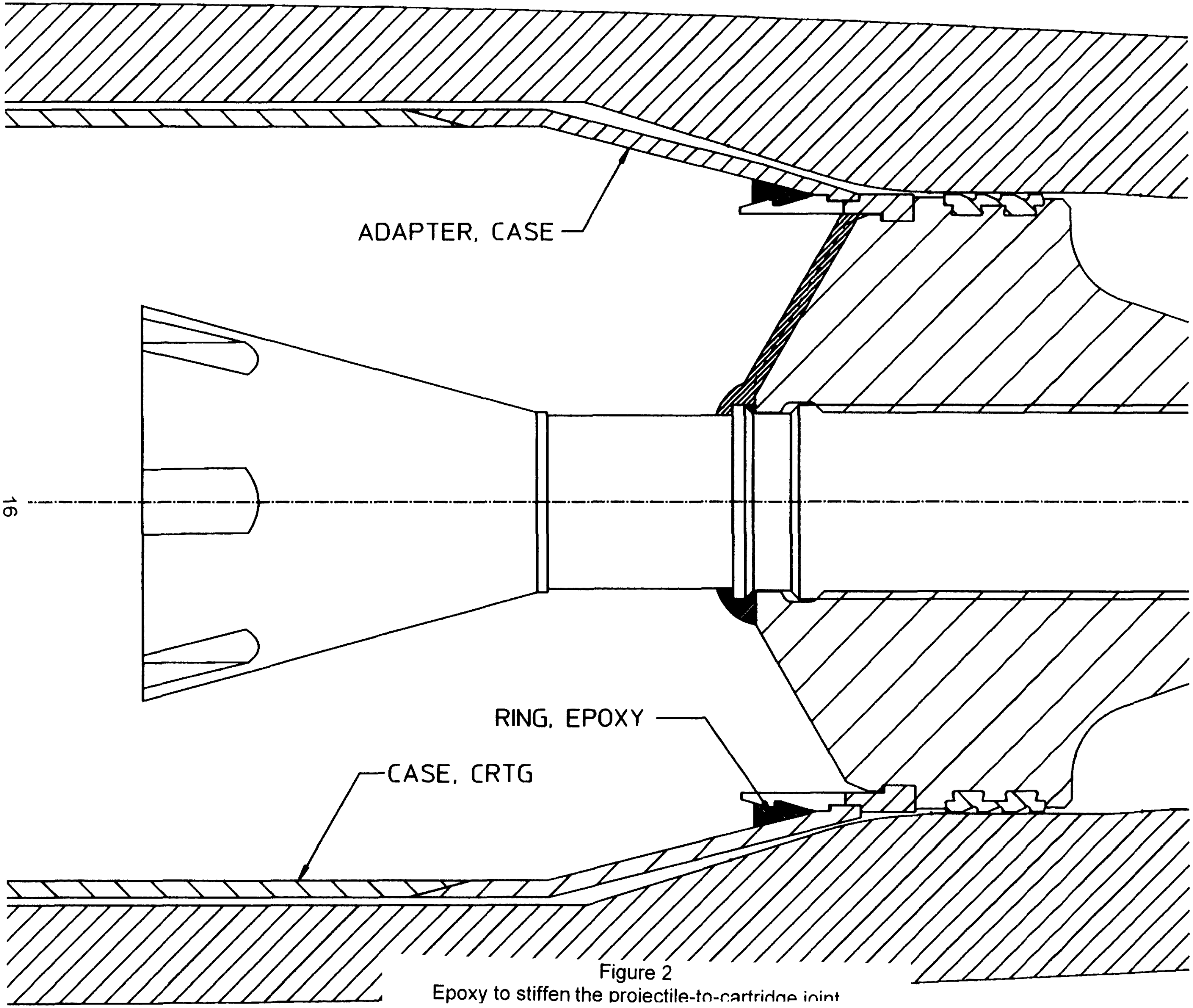

Figure 2
Epoxy to stiffen the projectile-to-cartridge joint

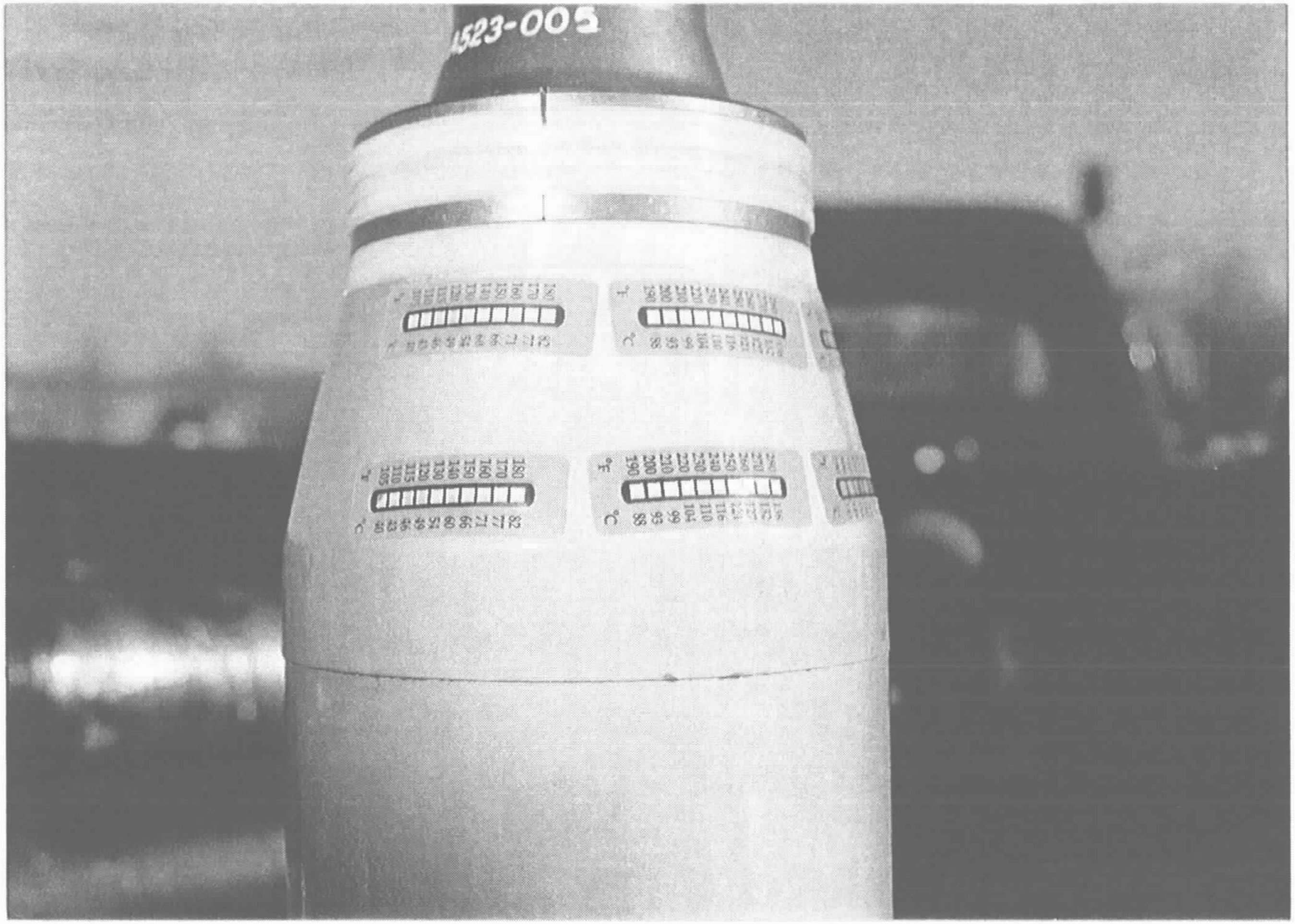

Figure 3
Temperature sensor labels applied to M865 case adapter

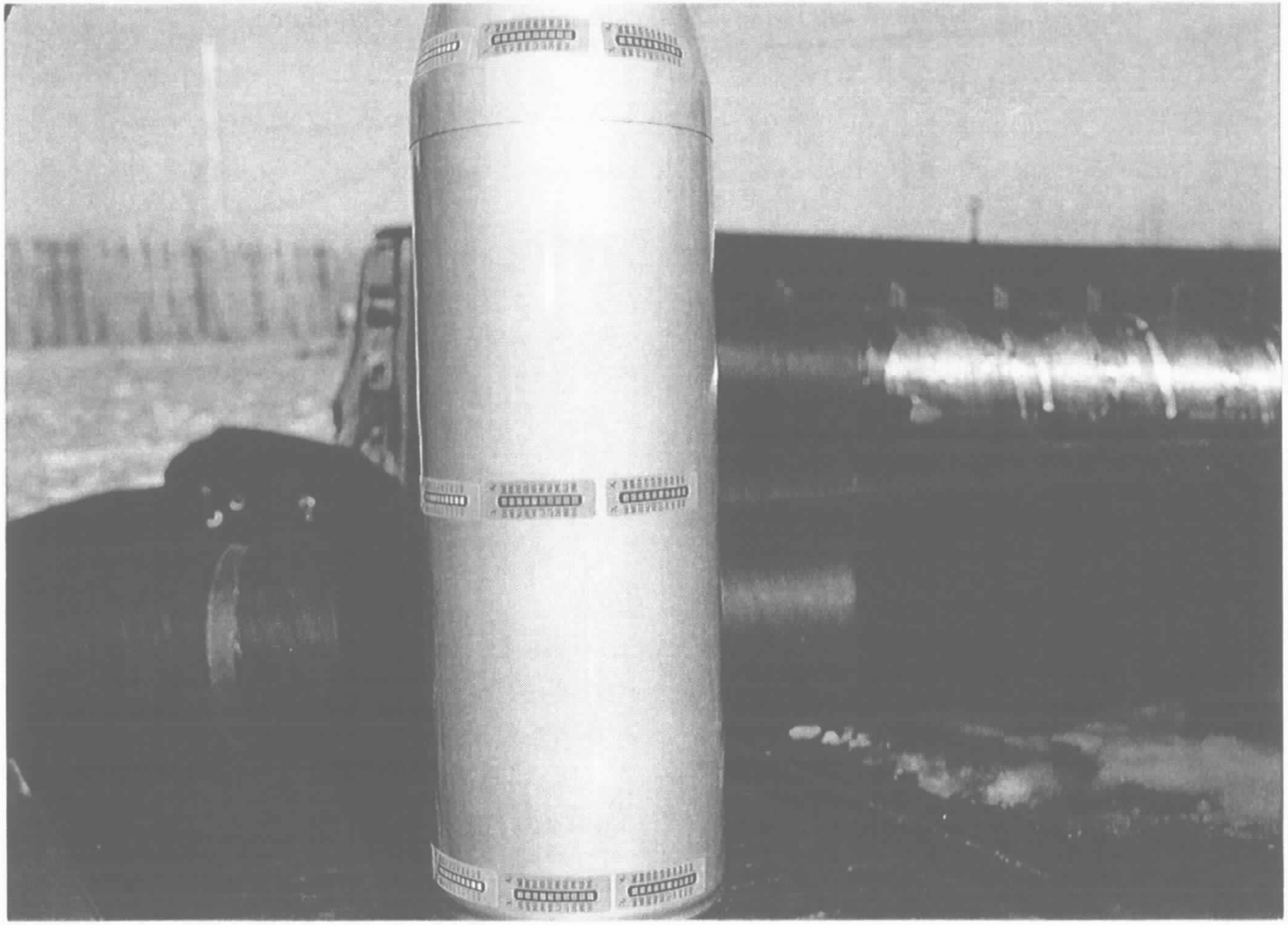

Figure 4
Temperature sensor labels applied to M865 cartridge case

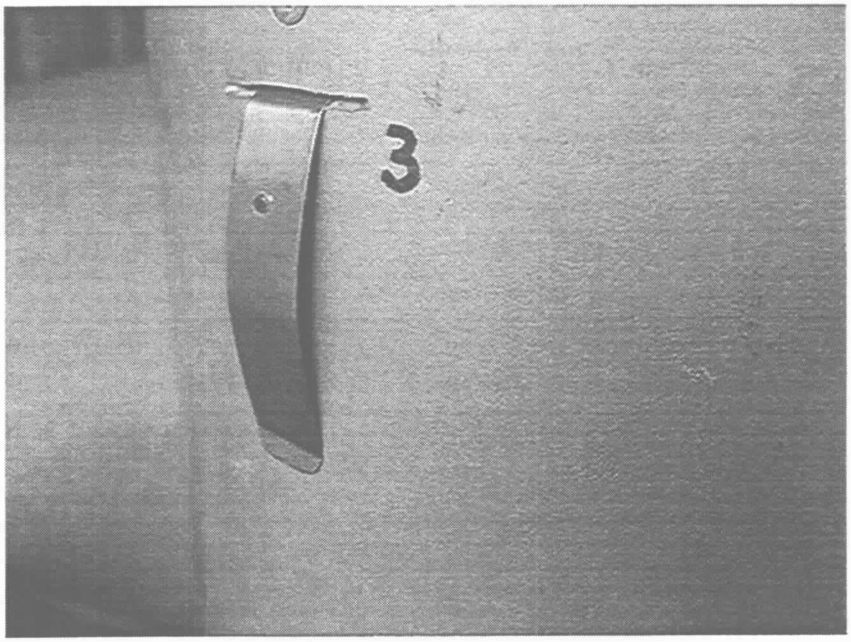

Figure 5
Sensor assemblies secured by countersunk screw (angle view)

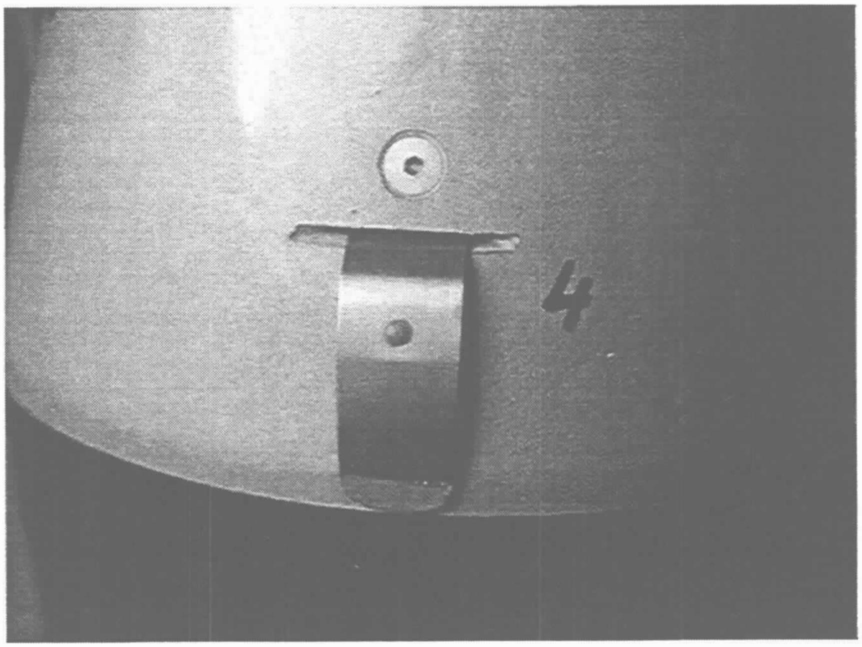

Figure 6
Sensor assemblies secured by countersunk screw (front view)

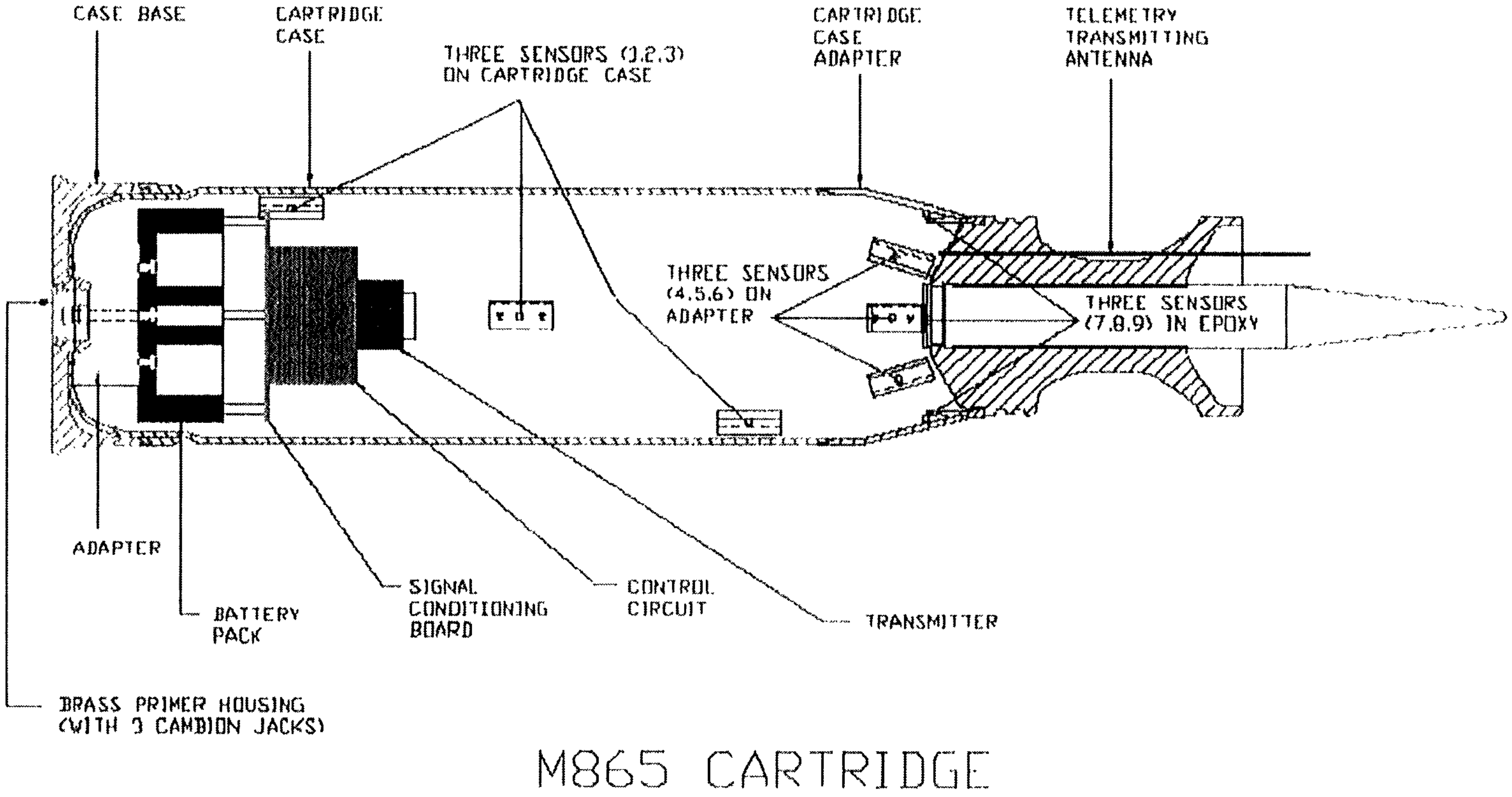

Figure 7
TM cartridge internal components

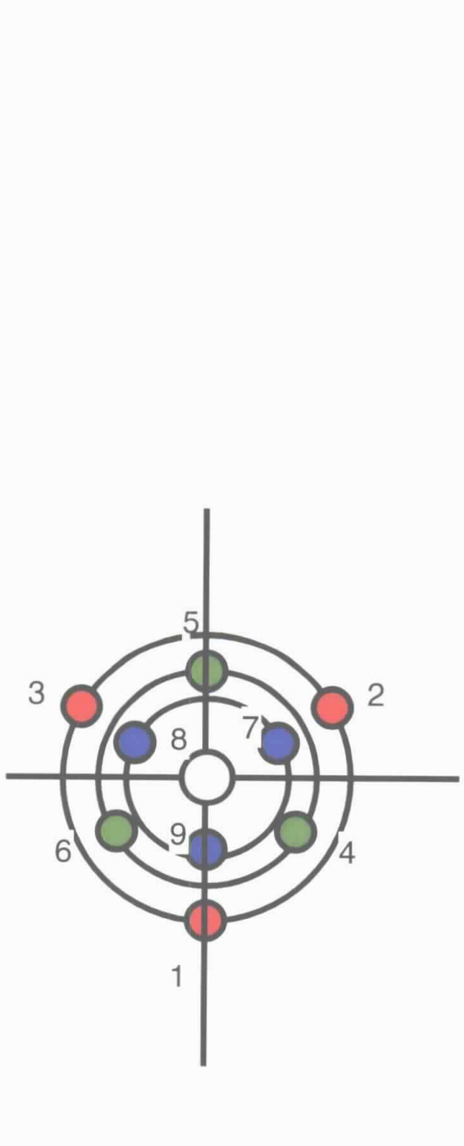

Figure 8
Sensor orientation (sensors 1 and 9 in alignment)

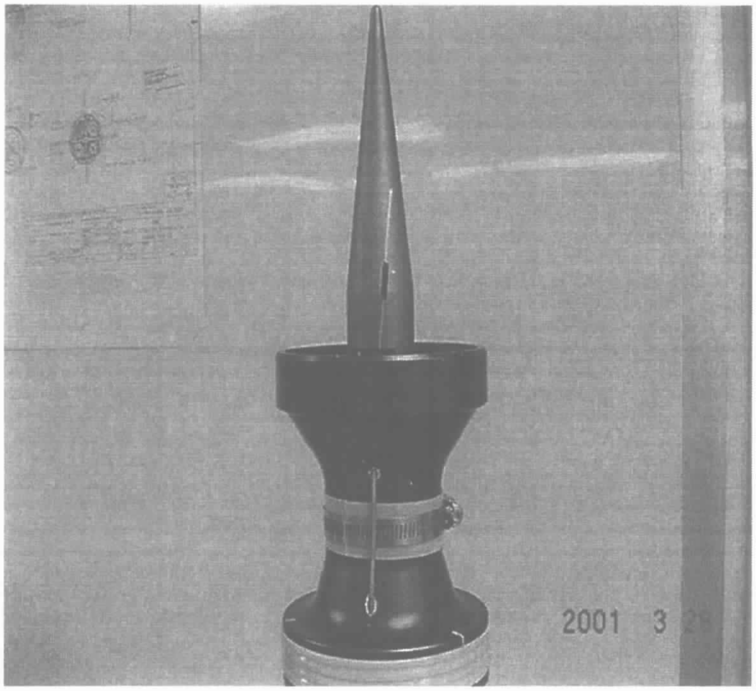

Figure 9
TM transmitting antenna

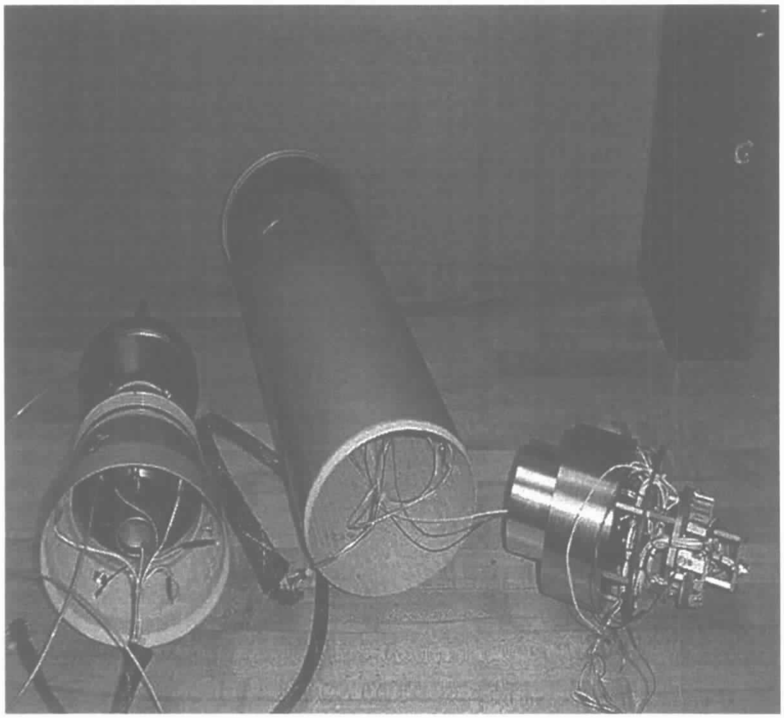

Figure 10
TM cartridge with projectile/case adapter and case base/cartridge case

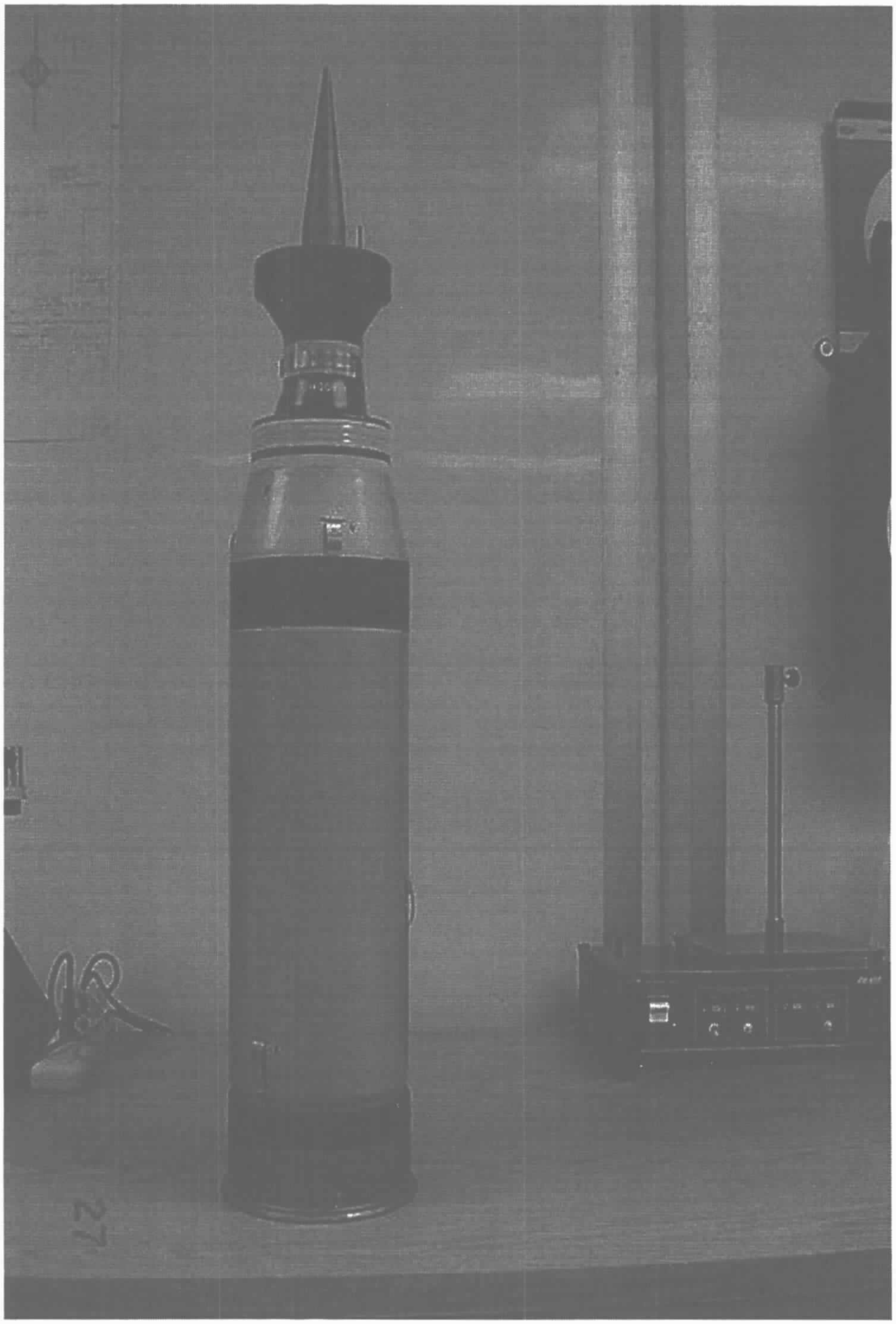

Figure 11
Completed TM unit

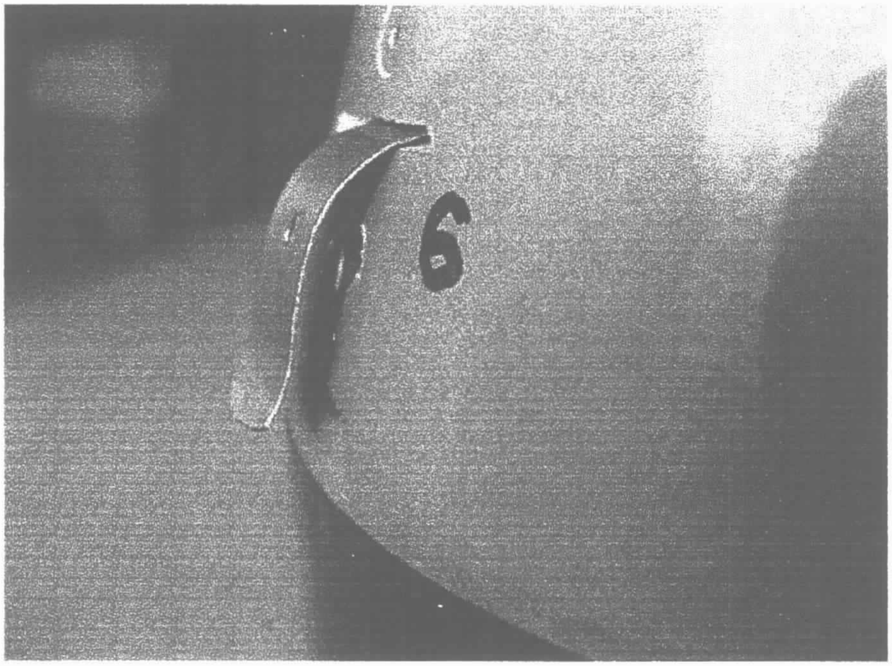

Figure 12
Damaged contact strip

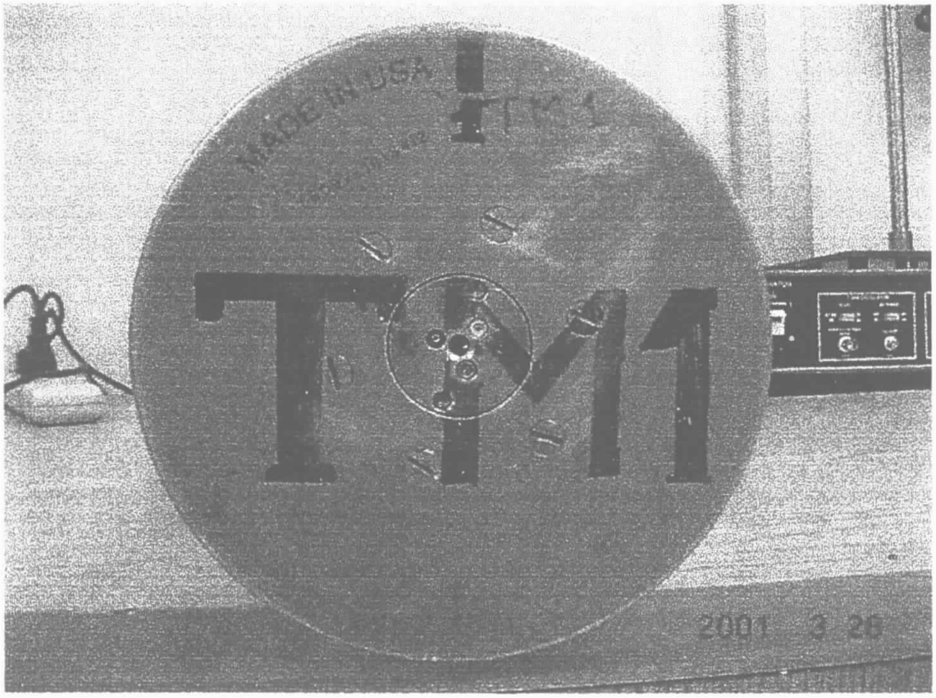

Figure 13
TM unit identification number and 12 o'clock index mark

TEMPERATURE TELEMETRY TEST APG TWII 3-13-01(TEST 1)

M256 TUBE S/N 6385 (FT. BENNING RETURN)
TANK. M1A1, LATE PROD (S/N UNKNOWN)
BORE EVACUATOR: YES
TEST DIR: PAUL DURKIN
LOADER: PAUL DURKIN

M655 LOT ORI00H703-002A (REWORKED FOR PRIMER INSPECTION)
CONDITIONED TO 0C
TM UNITS NOT TEMERATURE CONDITIONED

NOTES

"TOC"-TIME OF CHAMBERING (BREECH CLOSE)
"TOF"-TIME OF FIRE
"TIC"-TIME IN CHAMBER (TIME BETWEEN BREECH CLOSE AND TRIGGER PULL)
"TBF"-TIME BETWEEN FIRINGS (TRIGGER PULLS)
P-GUN TUBE PROOF ROUNDS
W-WARMER ROUNDS (USED TO HEAT GUN TUBE, M865/C785)
TM-TELEMERTY UNIT
"CUM ROUNDS"-CONSECUTIVE ROUND COUNT (ALL TYPES)
"INSERT"-SENSOR INSERTION, THE IDENTIFIER OF WHAT TEST (FIRST DIGIT) AND WHAT USE (SECOND DIGIT) OF TM UNIT "1-1" INDICATES FIRST USE OF FIRST TEST,
"3-6" INDICATES SIXTH USE OF THIRD TEST
IN THE CASE OF TM UNIT INSERTION, "TBF" IS TIME BETWEEN LAST ROUND FIRED AND TM UNIT CHAMBERING (BREECH CLOSE)

ROUND	TOC	TOF	TIC	TBF	REMARKS	CUM ROUNDS	INSERT
P1		10:37			FIRST OF THREE PROOF RONDS	1	
P2		10 41			TOF SECONDS NOT RECORDED	2	
P3		10:43			ROUNDS FIRED REMOTELY	3	
W1	10:53.33	10:54 21	0.48			4	
W2	10 54:30	10.54.32	0.02	0:11		5	
W3	10 54 42	10:54:44	0 02	0 12		6	
W4	10 54.54	STUCK			WOULD NOT CHAMBER-RESIDUE STUCK 2 IN OUT	7	
W5	11 18:08	11.19:29	1.21			7	
W6	11.19:38	11.19:40	0 02	0 11		8	
W7	11:19:47	11 19.49	0:02	0:09		9	
W8	11:19:58	11 20 00	0.02	0:11		10	
TM1	11.20:13		17.00	0.13	DECHAMBERD @ 11:37:25		1-1
W9	11:53:25	11 53:54	0 09			11	
W10	11:54:03	11:54:05	0:02	0 11		12	
W11	11:54.14	11:54:16	0.02	0.11		13	
W12	11:54 26	11:54.28	0 02	0:12		14	
TM2	11 54 39		37:??*	0:11	DECHAMBER @ 13.31:24		1-2

*ALTHOUGH DECHAMBERED AFTER RETURNING FROM LUNCH, BATTERY LIFE APPROX 38 MIN

Figure 14
Test times from test 1 (3-31-01)

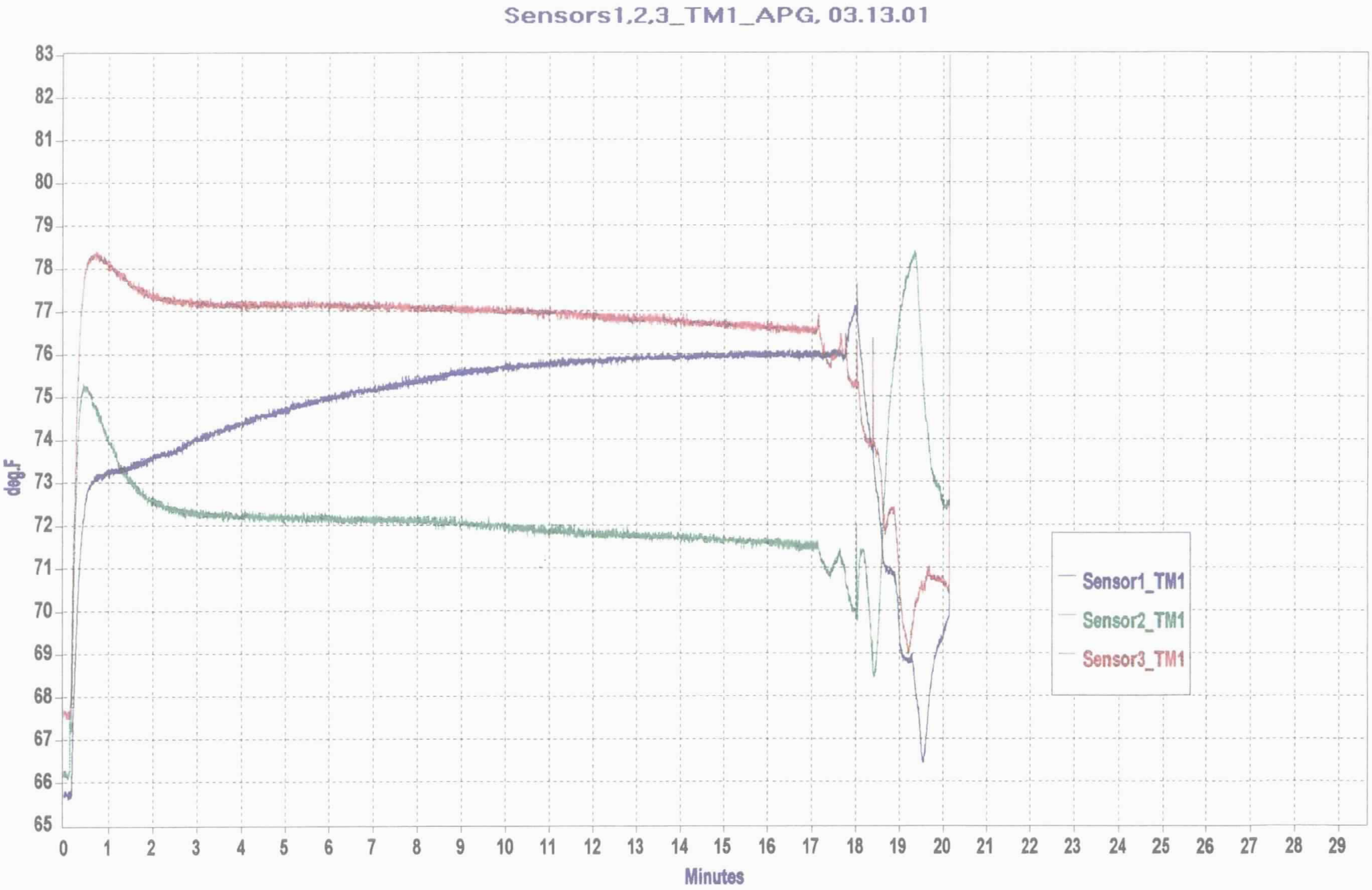

Figure 15
Time/temperature curves for TM 1 (sensors 1, 2, 3)

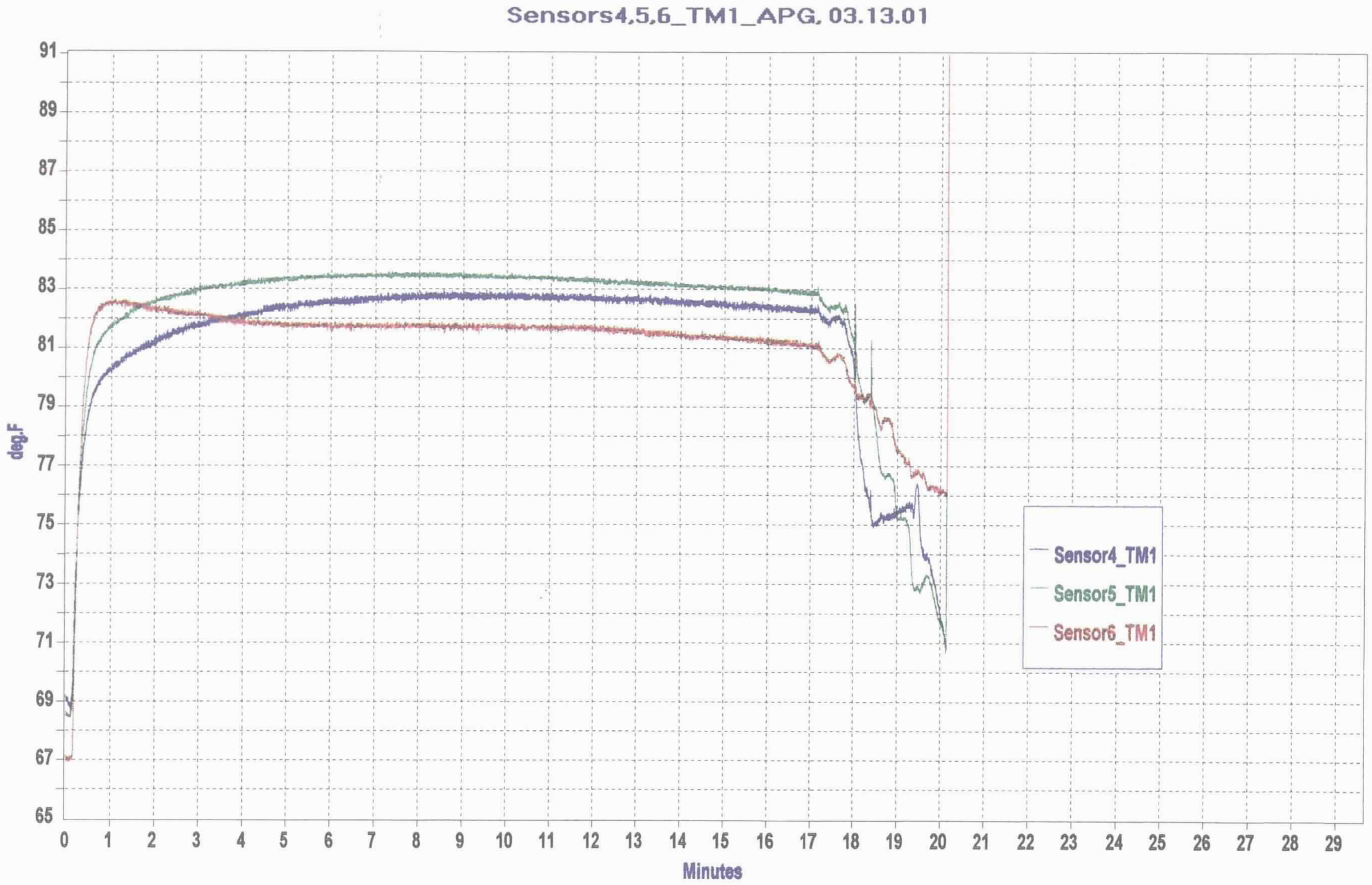

Figure 16
Time/temperature curves for TM 1 (sensors 4, 5, 6)

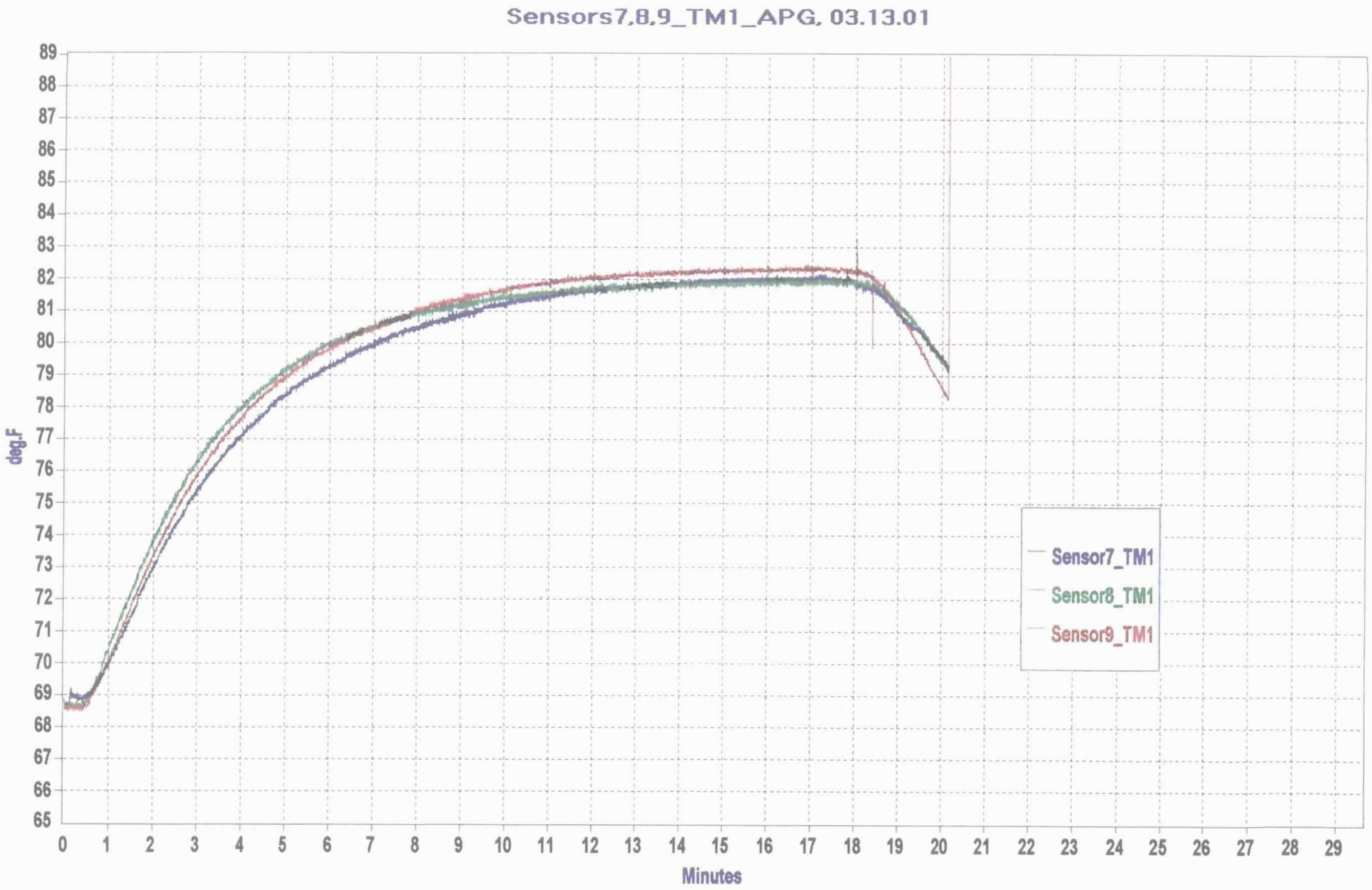

Figure 17
Time/temperature curves for TM 1 (sensors 7, 8, 9)

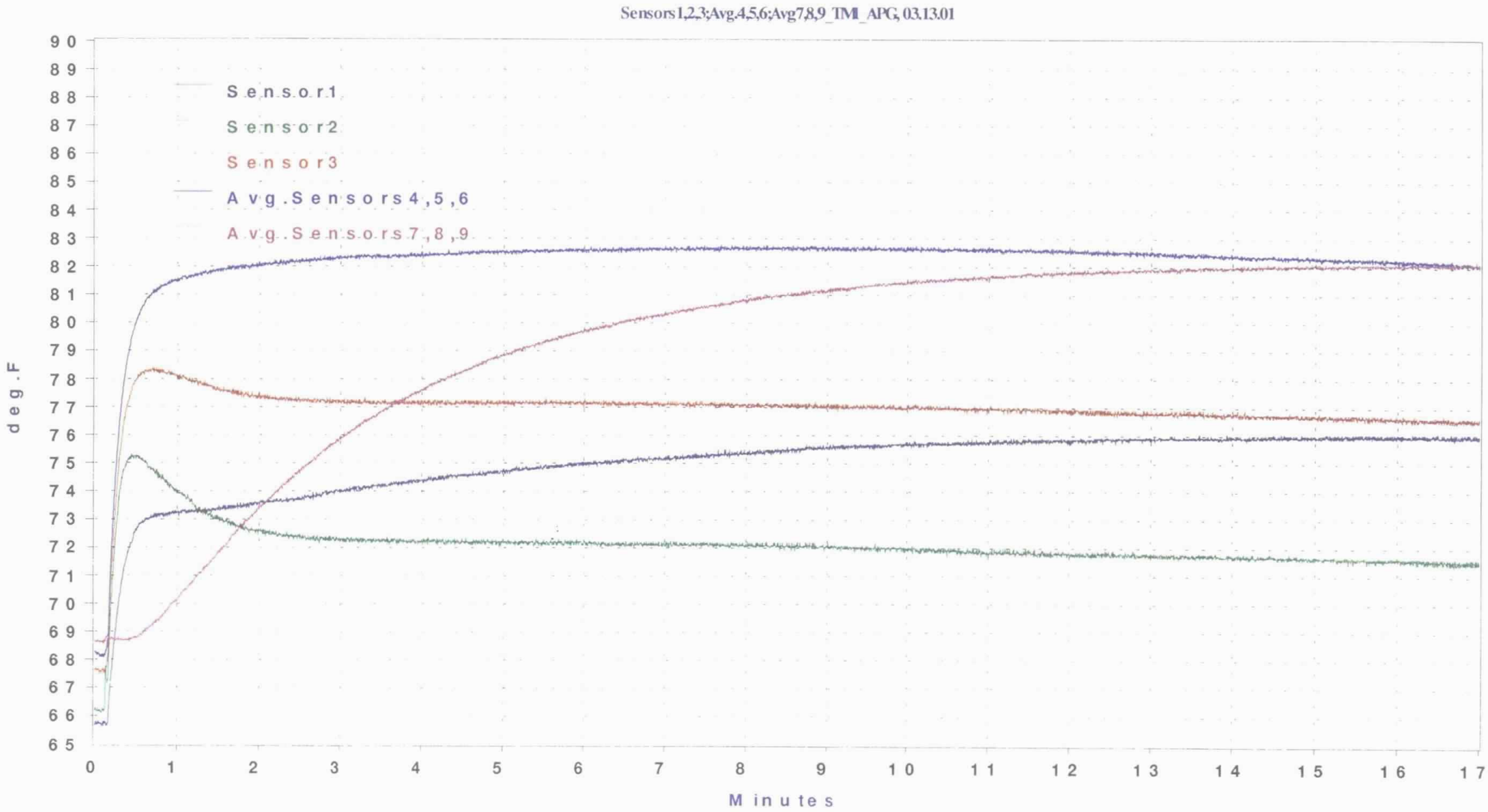

Figure 18
Abbreviated data for insertion 1-1

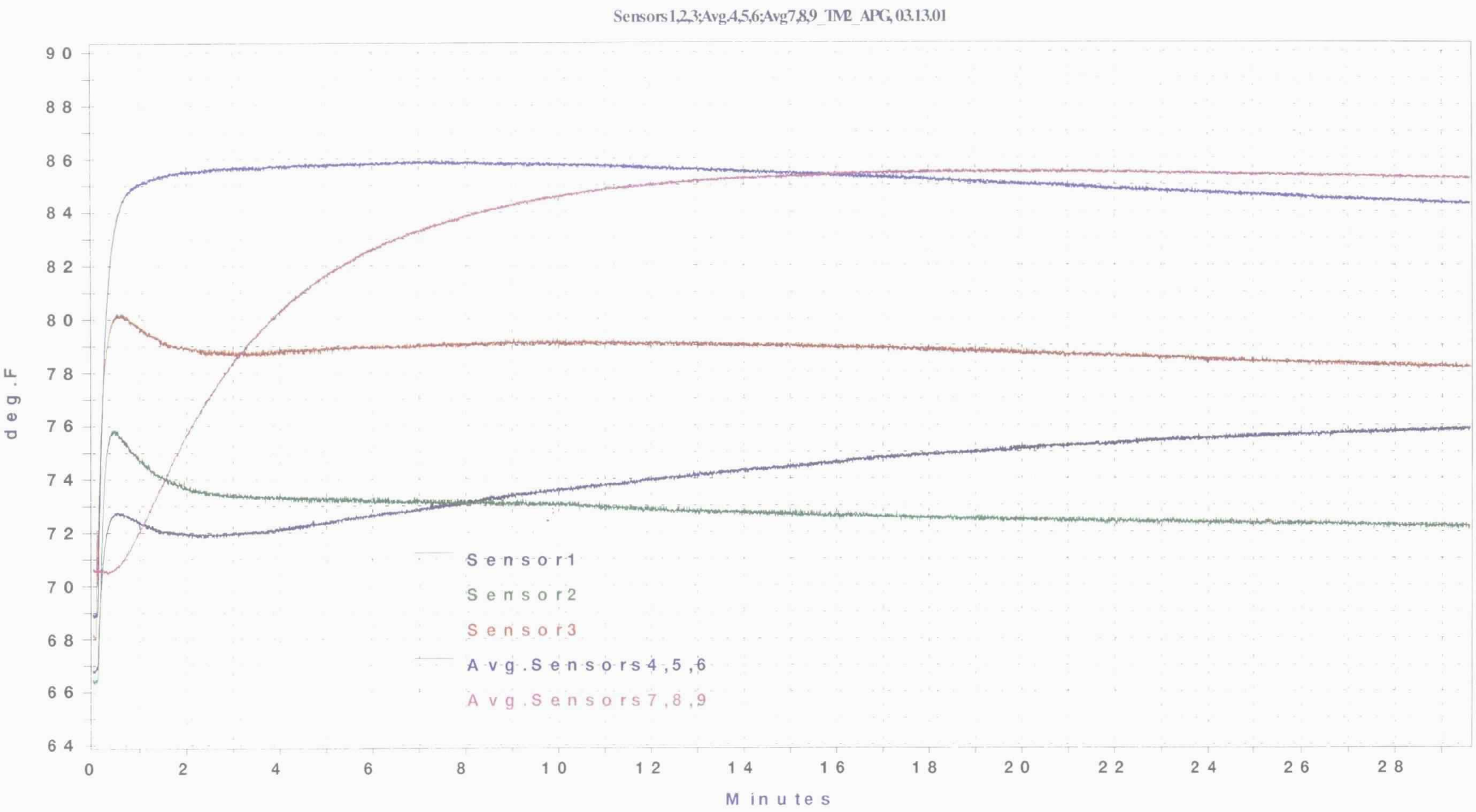

Figure 19
Abbreviated data for insertion 1-2

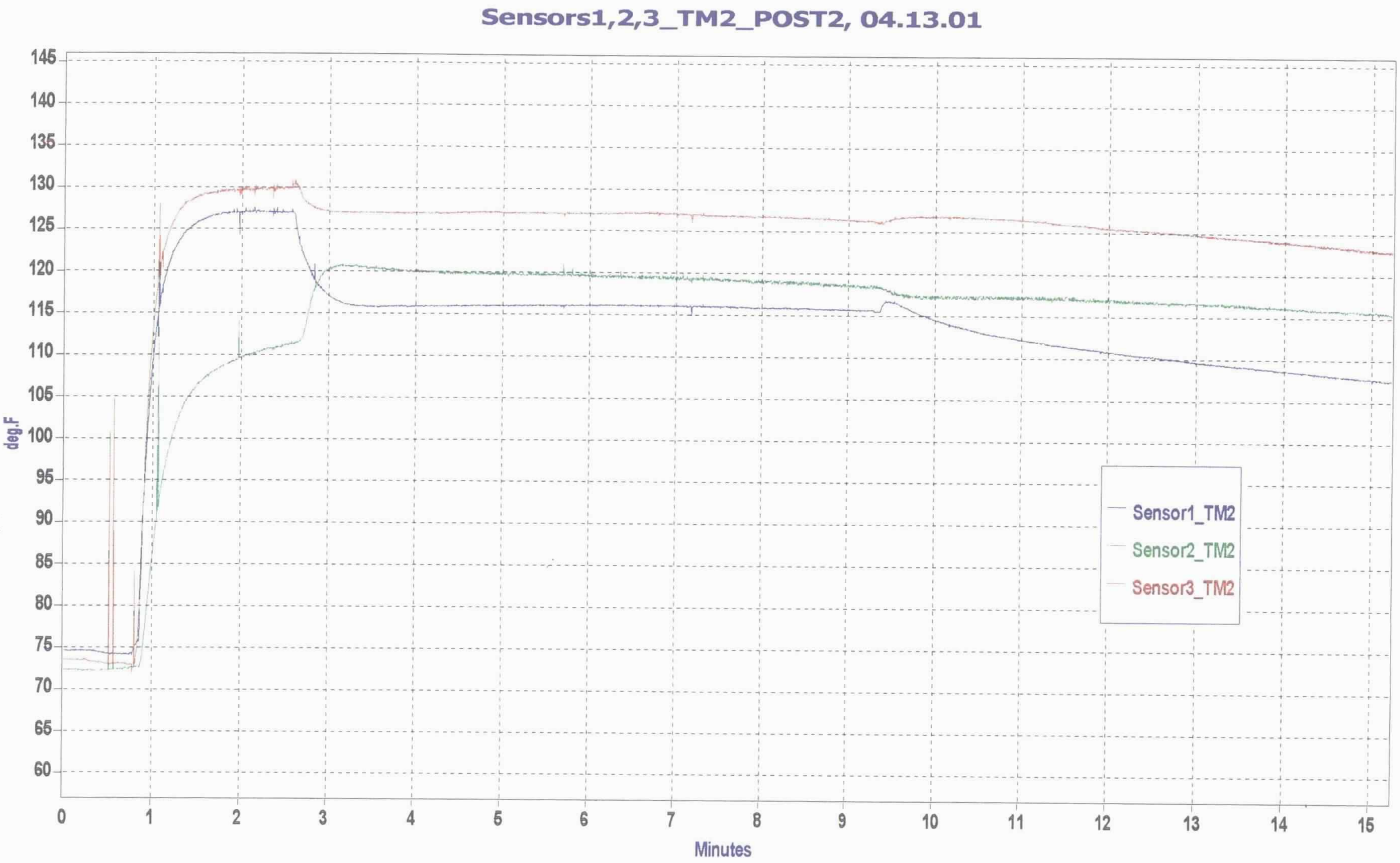

Figure 20
Temperature curves for sensors 1, 2,3 (diagnostic test)

TELEMETRY TEST SUMMARY (TEMPERATURES AFTER 4 AND 5 MINS)					
TEST 1 (13 MARCH 2001)					
		4 MINS	5 MINS		
TM INSERTION		S4/5/6 MAX (AVG), DEG F	S4/5/6 MAX (AVG), DEG F	CUMUL RDS	
1-1		82	83	10	
1-2		85	86	14	
TEST 2 (5 SEPT 2001)					
2-1		82	83	8	
2-2		111	114	23	
2-3		123	126	38	
2-4		NOT CHAMBERED	NOT CHAMBERED	46	
2-5		118	122	54	
2-6		131	133	61	
2-7		142	145	76	
2-8		NOT CHAMBERED	NOT CHAMBERED	84	
TEST 3 (6 SEPT 2001)					
3-1		103	104	15	
3-2		122	124	30	
3-3		123	125	38	
3-4		135	138	53	
3-5		142	145	68	
3-6		137	142	76	

Figure 21
Telemetry test summary (temperatures after 4 and 5 min)

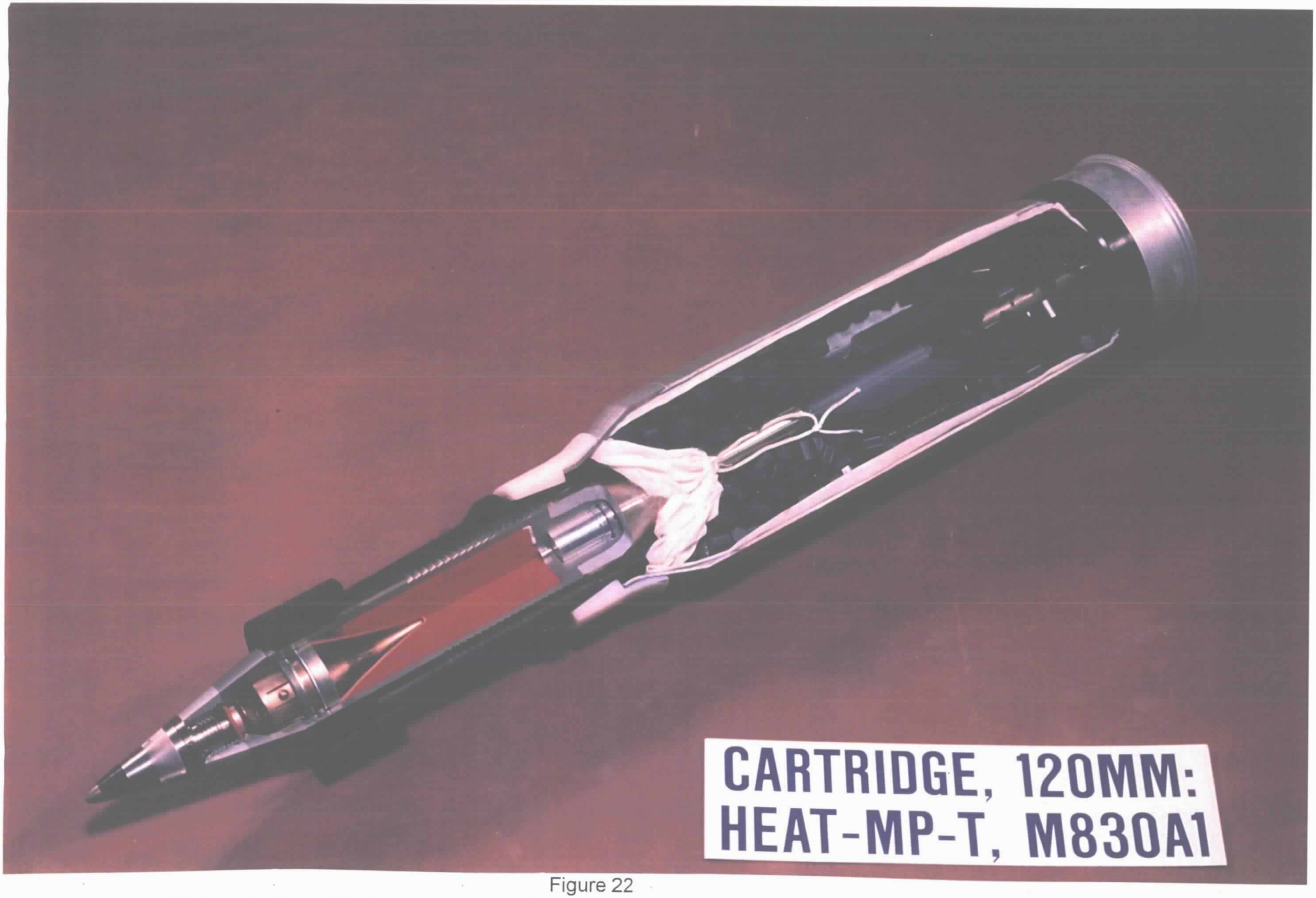

Figure 22
High explosive antitank multipurpose with tracer (HEAT-MP-T) M830A1 cartridge configuration

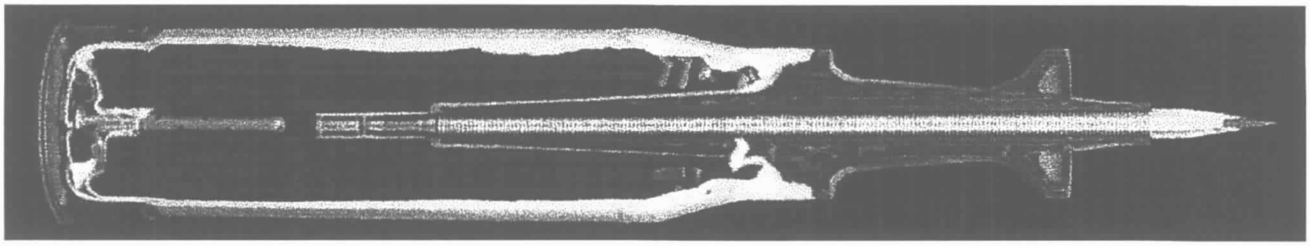

Figure 23
Armor penetrating fin stabilized discarding sabot with tracer (APFSDS-T)
M829A2 cartridge configuration

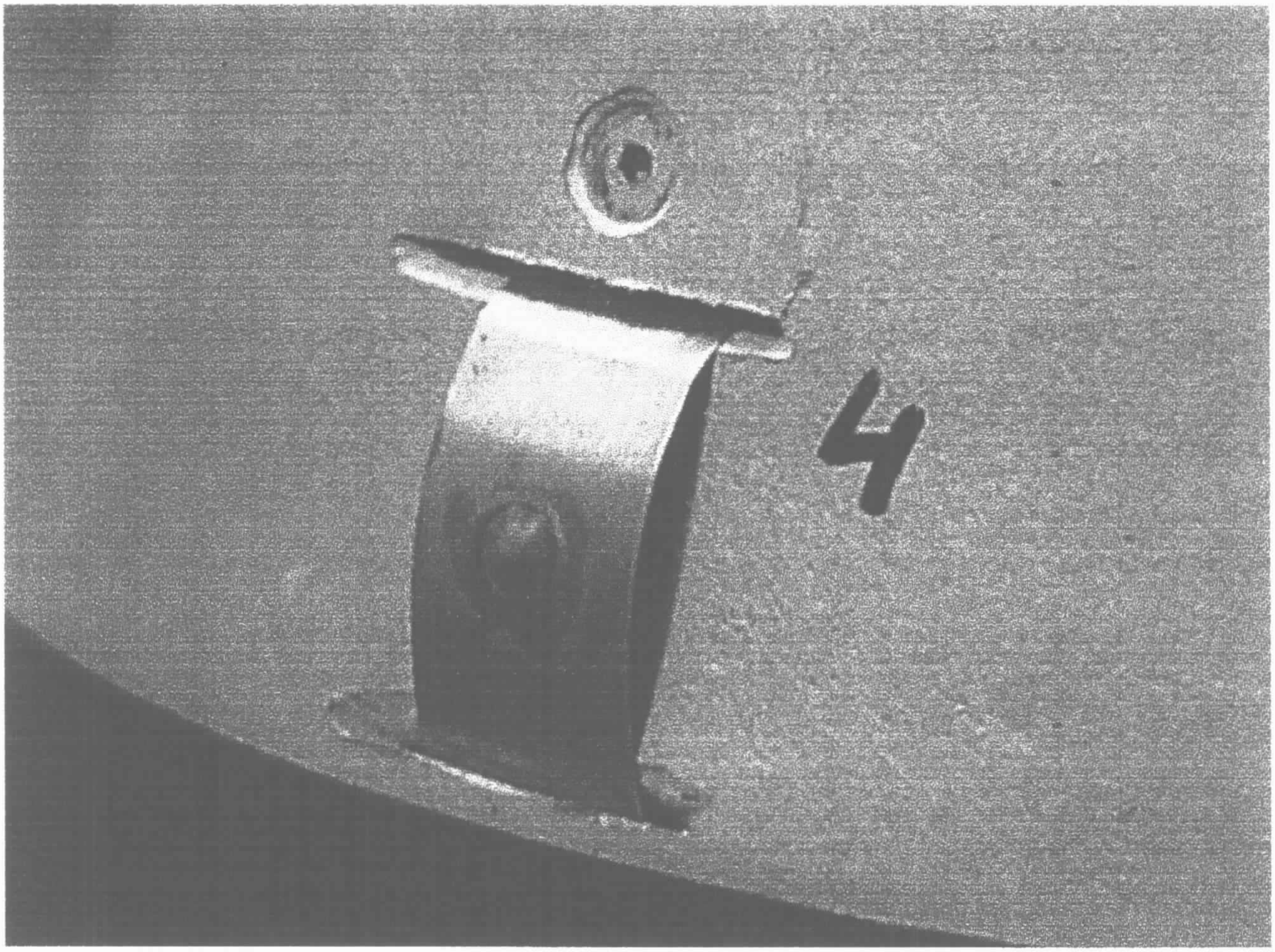

Figure 24
Improved temperature sensors configuration

TEMPERATURE TEMEMETRY TEST APG BARRICADE B-1 9-5, 6-01

M256 TUBE S/N 6385 (FT. BENNING RETURN)
FIXED ACCURACY MOUNT
BORE EVACUATOR. YES
TEST DIR. TOM DEAL
LOADER. VARIOUS

M655/C785 LOT OR100H703-002A (REWORKED FOR PRIMER INSPECTION)
M830A1/C791 LOT MHM94B130-005
M829A2/C792 LOT

CONDITIONED TO 0C (FAILURE OF COND BOXES-SOME ROUNDS SLIGHTLY WARMER)
TM UNITS NOT TEMPERATURE CONDITIONED

NOTES

"TOC"-TIME OF CHAMBERING (BREECH CLOSE)
"TOF"-TIME OF FIRE
"TIC"-TIME IN CHAMBER (TIME BETWEEN BREECH CLOSE AND TRIGGER PULL)
"TBF"-TIME BETWEEN FIRINGS (TRIGGER PULLS)
P-GUN TUBE PROOF ROUNDS
W-WARMER ROUNDS (USED TO HEAT GUN TUBE, M865/C785)
TM-TEMEMETRY UNIT
"CUM ROUNDS"-CONSECUTIVE ROUND COUNT (ALL TYPES)
"INSERT"-SENSOR INSERTION, THE IDENTIFIER OF WHAT TEST (FIRST DIGIT) AND WHAT USE (SECOND DIGIT) OF TM UNIT. "1-1" INDICATES FIRST USE OF FIRST TEST,
"3-6" INDICATES SIXTH USE OF THIRD TEST
IN THE CASE OF TM UNIT INSERTION, "TBF" IS TIME BETWEEN LAST ROUND FIRED AND TM UNIT CHAMBERING (BREECH CLOSE)

9/5/2001	ROUND	TOC	TOF	TIC	TBF	REMARKS	CUM ROUNDS	INSERT
TEST 2	M865	10:35:35	10:36:07	0:31			1	
	M865	10:36:21	10:38:20	1:59	2:13		2	
	M865	10:38:33	10:38:41	0:08	0:21		3	
	M865	10:38:58	10:40:57	1:59	2:16		4	
	M865	10:41:12	10:41:21	0:09	0:24		5	
	M865	10:41:38	10:43:40	2:02	2:19		6	
	M865	10:43:52	10:44:04	0:12	0:24		7	
	M865	10:44:24	10:46:29	2:05	2:25		8	
	TM2	10:47	10:53	6:00	0:31±	SOME TIME LOST IN CLOSING BREECH		2-1
	M829A2	10:57:43	10:57:51	0:08	11:22		9	
	M829A2	10:58:07	11:00:08	2:01	2:17		10	
	M829A2	11:00:21	11:00:27	0:06	0:19		11	
	M829A2	11:00:44	11:02:45	2:01	2:18		12	
	M829A2	11:02:59	11:03:06	0:07	0:21		13	
	M829A2	11:03:26	11:05:26	2:00	2:20		14	
	M829A2	11:05:37	11:05:44	0:07	0:18		15	
	M829A2	11:06:02	11:08:04	2:02	2:20		16	
	M829A2	11:08:18	11:08:24	0:06	0:20		17	
	M829A2	11:08:38	11:10:38	2:00	2:14		18	
	M829A2	11:10:50	11:10:56	0:06	0:18		19	
	M829A2	11:11:17	11:13:36	2:01	2:22		20	
	M829A2	11:13:30	11:13:36	0:06	0:18		21	
	M829A2	11:13:50	11:15:52	2:02	2:16		22	
	M829A2	11:16:02	11:16:07	0:05	0:25		23	
	TM2	11:16:32	11:23:21	7:10	0:25			2-2

Figure 25
Temperature telemetry tests 2 and 3 at Aberdeen Proving Ground

9/5/2001 ROUND	TOC	TOF	TIC	TBF	REMARKS	CUM ROUNDS	INSERT
M830A1	11:28:21	11:28:29	0:08	12:22		24	
M830A1	11:28:51	11:30:51	2:00	2:22		25	
M830A1	11:31:04	11:31:10	0:06	0:19		26	
M830A1	11:31:31	11:33:33	2:02	2:23		27	
M830A1	11:33:48	11:33:53	0:05	0:20		28	
M830A1	11:34:12	11:36:12	2:00	2:19		29	
M830A1	11:36:25	11:36:30	0:05	0:18		30	
M830A1	11:36:49	11:38:30	2:19	2:00		31	
M830A1	11:38:46	11:38:53	0:07	0:23		32	
M830A1	11:39:12	11:41:13	2:01	2:20		33	
M830A1	11:41:26	11.41:32	0:06	0:19		34	
M830A1	11:41:52	11:43:53	2:01	2:21		35	
M830A1	11:44:06	11:44:14	0:08	0:21		36	
M830A1	11:44:32	11:46:35	2:03	2:21		37	
M830A1	11.46:50	11:46:56	0:06	0:21		38	
TM2	11:47:28	11:52:40	5:12	0:32			2-3
M865	11:55:45	11:55:53	0:08	3.23		39	
M865	11:56:04	11:58:04	2:00	2:11		40	
M865	11:58:13	11:58:19	0:06	0:15		41	
M865	11:58:29	12:00:30	2:01	2:11		42	
M865	12:00:40	12:00:45	0:05	0:15		43	
M865	12:00:58	12:03:03	2:05	2:18		44	
M865	12:03:13	12:03:19	0:06	0:16		45	
M865	12:03:31	12:05:31	2:00	3:12		46	
TM1					WOULD NOT CHAMBER-RESIDUE		2-4
M829A2	13:55:27	13:55:45	0:18	1:50:14		47	
M829A2	13:55:58	13:57:57	2:01	2:12		48	
M829A2	13:58:07	13:58:14	0:07	0:17		49	
M829A2	13:58:26	14:00:27	2:01	2:13		50	
M829A2	14:00:39	14:00:45	0:06	0:18		51	
M829A2	14:01:00	14:02:59	1:59	2:14		52	
M829A2	14:03:10	14:03:16	0:06	0:17		53	
M829A2	14:03:28	14:05:31	2:03	2:15		54	
TM2	14:06:24	14:11:30	5:06	0:53	AMMO NOT READY @ GUN, TM UNIT CHAMBERED EARLY		2-5
M829A2	14:12:51	14:12:57	0:06	1:27		55	
M829A2	14:13:11	14:15:12	2:01	2:15		56	
M829A2	14:15:24	14:15:31	0:07	0:19		57	
M829A2	14:15:43	14:17:44	2:01	2:13		58	
M829A2	14:17:58	14:18:05	0:07	0:21		59	
M829A2	14:18:18	14:20:18	2:00	2:13		60	
M829A2	14:20:31	14:20:41	0:10	0:23		61	
TM2	14:21:02	14:26:37	5:35	0:21			2-6
M830A1	14:37:42	14:37:50	0:08	17:09		62	
M830A1	14:38:03	14:40:03	2:00	2:13		63	
M830A1	14:40:15	14:40:21	0:06	0:18		64	
M830A1	14:40:37	14:42:37	2:00	2:16		65	
M830A1	14:42:50	14:42:56	0:06	0:19		66	
M830A1	14:43:09	14:45:11	2:02	2:15		67	
M830A1	14:45:23	14:45:28	0:05	0:17		68	
M830A1	14:45:43	14:47:42	1:59	2:14		69	
M830A1	14:48:01	14:48:08	0:07	0:26		70	
M830A1	14:48:26	14:50:26	2:00	2:18		71	
M830A1	14:50:37	14:50:43	0:06	0:17		72	
M830A1	14:50:56	14:52:58	2:02	2:15		73	
M830A1	14:53:15	14:53:21	0:06	0:23		74	
M830A1	14:53:36	14:55:37	1:59	2:16		75	
M830A1	14:55:49	14:55:54	0:05	0:17		76	
TM2	14:56:29	15:03:32	7:02	0:35			2-7

Figure 25
(continued)

9/5/2001	ROUND	TOC	TOF	TIC	TBF	REMARKS	CUM ROUNDS	INSERT
	M865	15:08:09	15:08:14	0:05	4:42		77	
	M865	15:08:27	15:10:27	2:00	2:13		78	
	M865	15:10:36	15:10:43	0:07	0:16		79	
	M865	15:10:55	15:12:54	1:59	2:11		80	
	M865	15:13:08	15:13:14	0:06	0:02		81	
	M865	15:13:27	15:15:24	1:57	2:10		82	
	M865	15:15:33	15:15:40	0:07	0.16		83	
	M865	15:15:51	15:17:52	2:01	2:12		84	
	TM2					WOULD NOT CHAMBER-RESIDUE		2-8

9/6/2001	ROUND	TOC	TOF	TIC	TBF	REMARKS	CUM ROUNDS	INSERT
Test 3								
	M829A2	8:39:05	8:39:40	0:35			1	
	M829A2	8:39:57:	8:41:58	2:01	2:18		2	
	M829A2	8:42:13	8:42:19	0:06	0:21		3	
	M829A2	8:42:33	8:44:30	1:57	2:11		4	
	M829A2	8:44:42	8:44:47	0:05	0:17		5	
	M829A2	8:45:01	8:47:01	2:00	2:14		6	
	M829A2	8:47:12	8:47:17	0:05	0:16		7	
	M829A2	8:47:30	8:49:30	2:00	2:13		8	
	M829A2	8:49:41	8:49:47	0:08	0:17		9	
	M829A2	8:50:01	8:52:01	2:00	2:14		10	
	M829a2	8:52:10	8:52:15	0:05	0:14		11	
	M829A2	8:52:27	8:54:28	2:01	2:13		12	
	M829A2	8:54:39	8:54:45	0:06	0:17		13	
	M829A2	8:54:56	8:56:55	1:59	2:10		14	
	M829A2	8:57:06	8:57:12	0:06	0:17		15	
	TM2	8:57:50	9:04:10	5:10	0:38			3-1
	M830A1	9:09:36	9:10:07	0:31	12:55		16	
	M830A1	9:10:26	9:12:25	1:59	2:18		17	
	M830A1	9:12:41	9:12:47	0:06	0:22		18	
	M830A1	9:13:03	9:15:03	2:00	2:16		19	
	M830A1	9:15:15	9:15:21	0:06	0:18		20	
	M830A1	9:15:40	9:17:40	2:00	2:19		21	
	M830A1	9:17:47	9:17:57	0:10	0:17		22	
	M830A1	9:18:11	9:20:12	2:01	2:15		23	
	M830A1	9:20:15	9:20:34	0:19	0.22		24	
	M830A1	9:20:42	9.22:43	2:01	2:09		25	
	M830A1	9:22:59	9:23:05	0:06	0:22		26	
	M830A1	9:23:18	9:25:19	2:01	2:14		27	
	M830A1	9:25:33	9:25:39	0:06	0:20		28	
	M830A1	9:25:52	9:27:51	1:59	2:12		29	
	M830A1	9:28:03	9:28:09	0:06	0:18		30	
	TM2	9:28:32	9:34:??	6:??	0:23			3-2
	M865	9:40:53	9:41:01	0:08	12:52		31	
	M865	9:41:20	9:43:19	1:59	2:18		32	
	M865	9:43:36	9:43:45	0:09	0:26		33	
	M865	9:43:58	9:45:58	2:00	2:13	DELAY-REMOVE RESIDUE	34	
	M865	9:57:01	9:57:44	0:44	1:46		35	
	M865	9:58:04	10:00:02	1:58	2:18		36	
	M865	10:00:14	10:00:24	0:10	0:22		37	
	M865	10:00:40	10:02:41	1:59	2:17		38	
	TM	10:03:05	10:13:26	10:21	0:24			3-3
	M829A2	10:40:12	10:40:21	0:09	0.37:40		39	
	M829A1	10:03:05	10:42:41	2:01	2:20		40	
	M829A1	10:42:56	10:43:03	0:07	0:22		41	
	M829A1	10:43:17	10:45:17	2:00	2:14		42	
	M829A1	10:45:35	10:45:41	0:06	0:24		43	
	M829A1	10:45:57	10:47:58	2:01	2:17		44	
	M829A1	10:48:12	10:48:19	0:07	0:21		45	

Figure 25
(continued)

9/6/2001	ROUND	TOC	TOF	TIC	TBF	REMARKS	CUM ROUNDS	INSERT
	M829A1	10:48:33	10:50:33	2:00	2:14		46	
	M829A1	10:50:48	10:50:54	0:06	0:21		47	
	M829A1	10:51:10	10:53:11	2:01	2:17		48	
	M829A1	10:53.25	10:53:31	0:06	0:20		49	
	M829A1	10:53:45	10:55:45	2:00	2:14		50	
	M829A1	10:56:01	10:56:06	0.05	0:11		51	
	M829A1	10:56:21	10:58:23	2:02	2:17		52	
	M829A1	10:58:36	10:58:44	0:08	0:21		53	
	TM2	10:59:10	11:0?:??	?:??	0:26			3-4
	M830A1	11:42:12	11:42:20	0.08	0:43:36		54	
	M830A1	11:42:42	11:44:42	2:00	2:22		55	
	M830A1	11:44:56	11:45:02	0:06	0:20		56	
	M830A1	11:45:18	11:47:21	2:03	2:19		57	
	M830A1	11:47:37	11:47:43	0:06	0:22		58	
	M830A1	11:48:02	11:50:02	2:00	2:19		59	
	M830A1	11:50:17	11:50:23	0:06	0:21		60	
	M830A1	11:50:38	11:52:40	2:02	0:17		61	
	M830A1	11:52:56	11:53:02	0:06	0:22		62	
	M830A1	11:53:23	11:55:23	2:00	2:21		63	
	M830A1	11:55:39	11:55:44	0:05	0:21		64	
	M830A1	11:56:01	11:58:01	2:00	2:17		65	
	M830A1	11:58:16	11:58:23	0:07	0:22		66	
	M830A1	11:58:43	12:00:43	2:00	2:20		67	
	M830A1	12:00:58	12:01:04	0:06	0:21		68	
	TM2	12:01:25	12:11:??	10:??	0:21			3-5
	M865	12:13:31	12:13:42	0:11	12:38		69	
	M865	12:13:59	12:16:01	2:02	2:19		70	
	M865	12:16:15	12:16:23	0:07	0:22		71	
	M865	12:16:38	12:18:38	2:00	2:15		72	
	M865	12:22:09	12:22:39	0:30	4:04	RESIDUE, BUT CHAMBERD OK	73	
	M865	12:23:01	12:25:01	2:00	2:22		74	
	M865	12:25:18	12:25:26	0:08	0:25		75	
	M865	12:25:39	12:27:39	2:00	2:13		76	
	TM1	12:28:13	12:58:??	30:??	0:34			3-6

Figure 25
(continued)

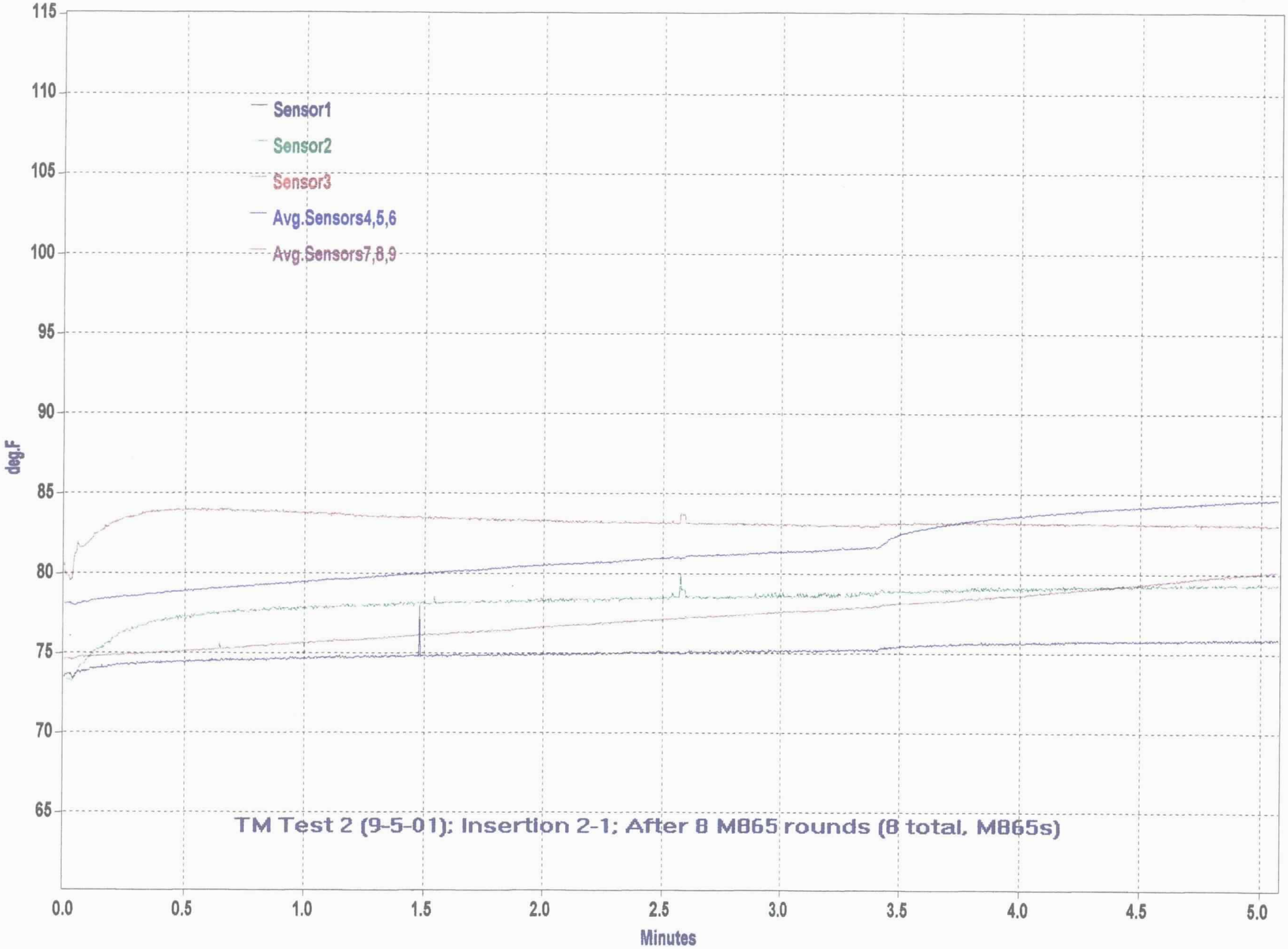

Figure 26
TM test 2, insertion 2-1 (8 M865 rounds)

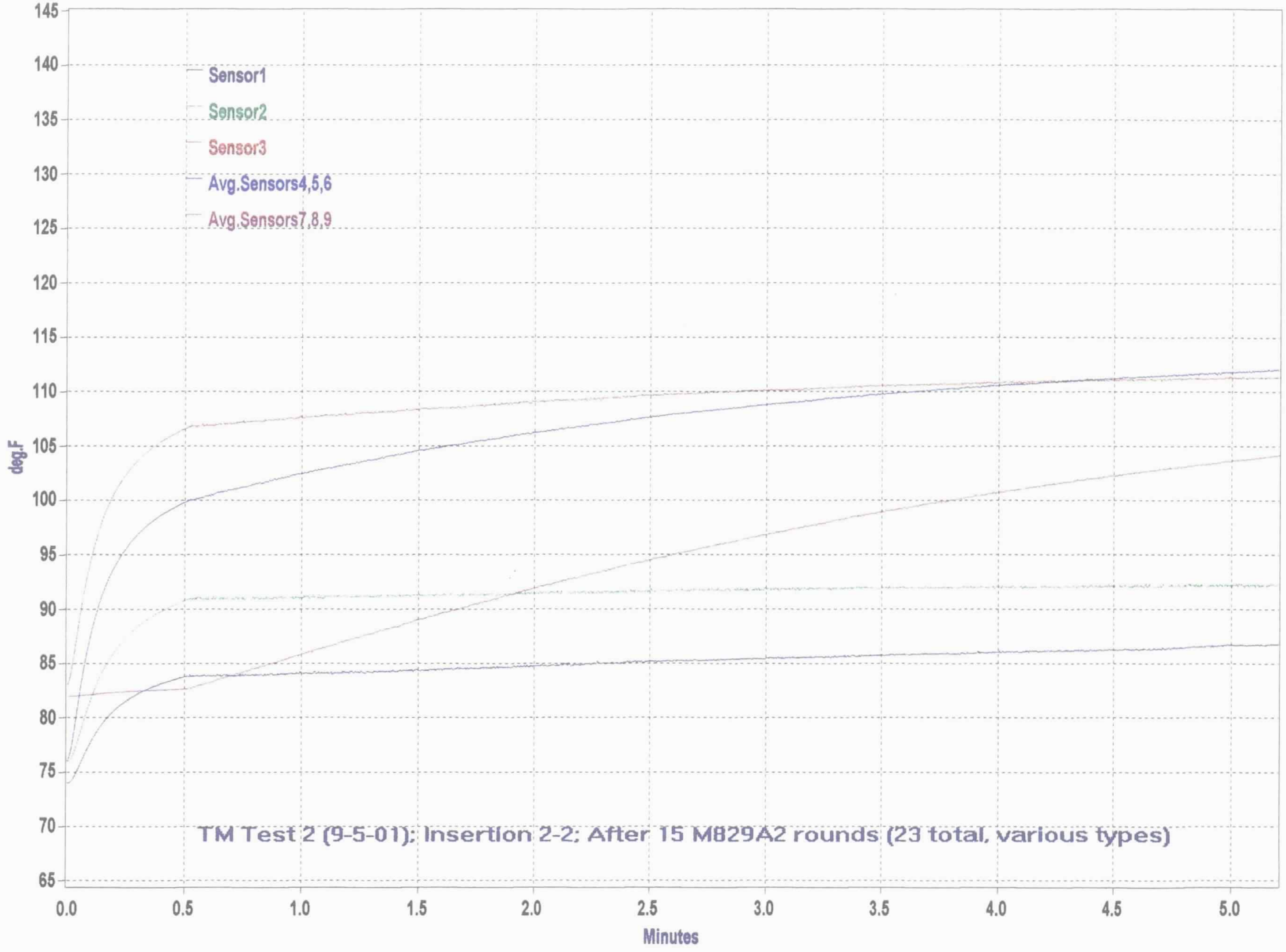

Figure 27
TM test 2, insertion 2-2, (15 M829A2 rounds; total 23 various types)

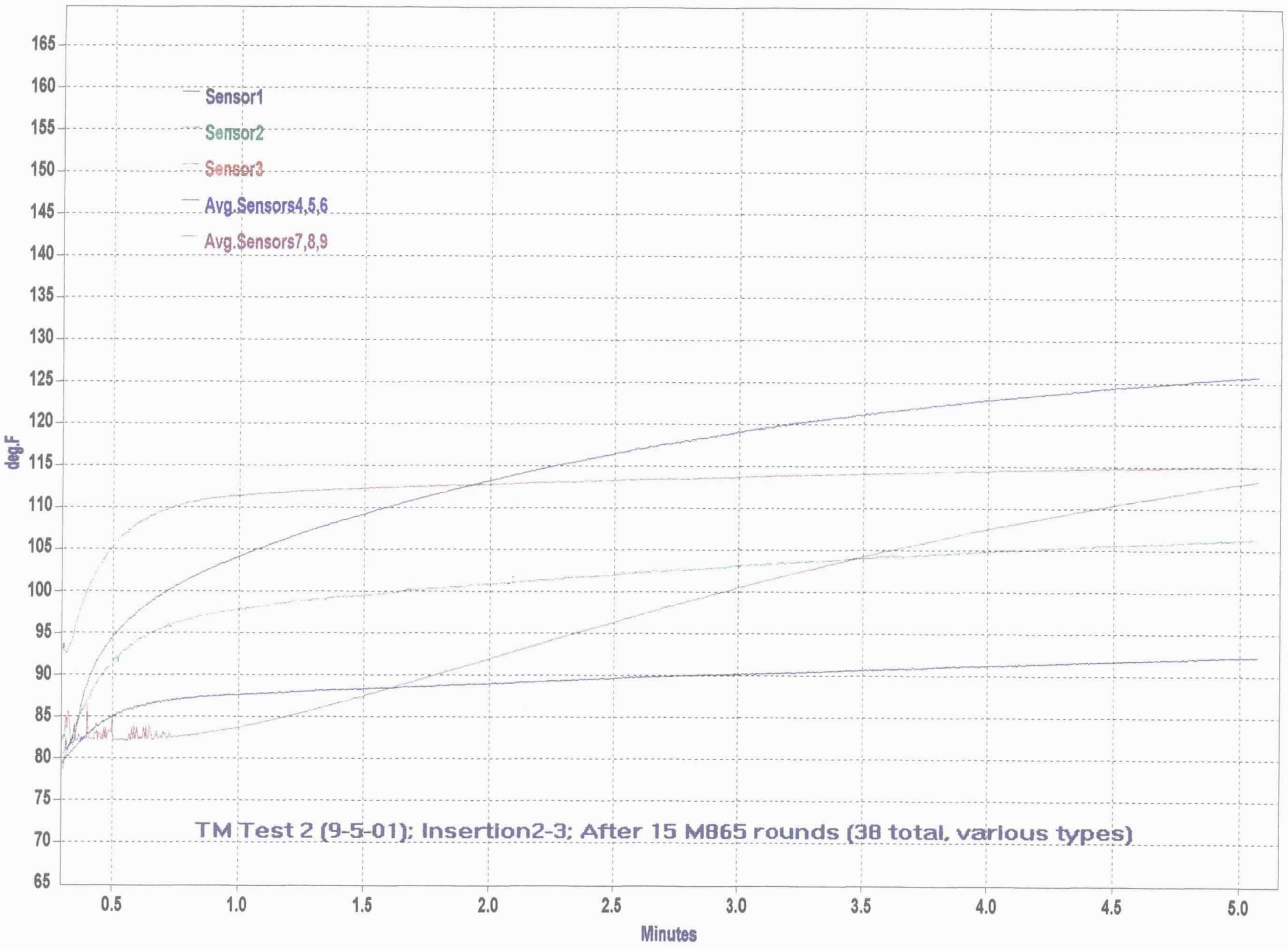

Figure 28
TM test 2, insertion 2-3 (15 M865 rounds; total 38 various types)

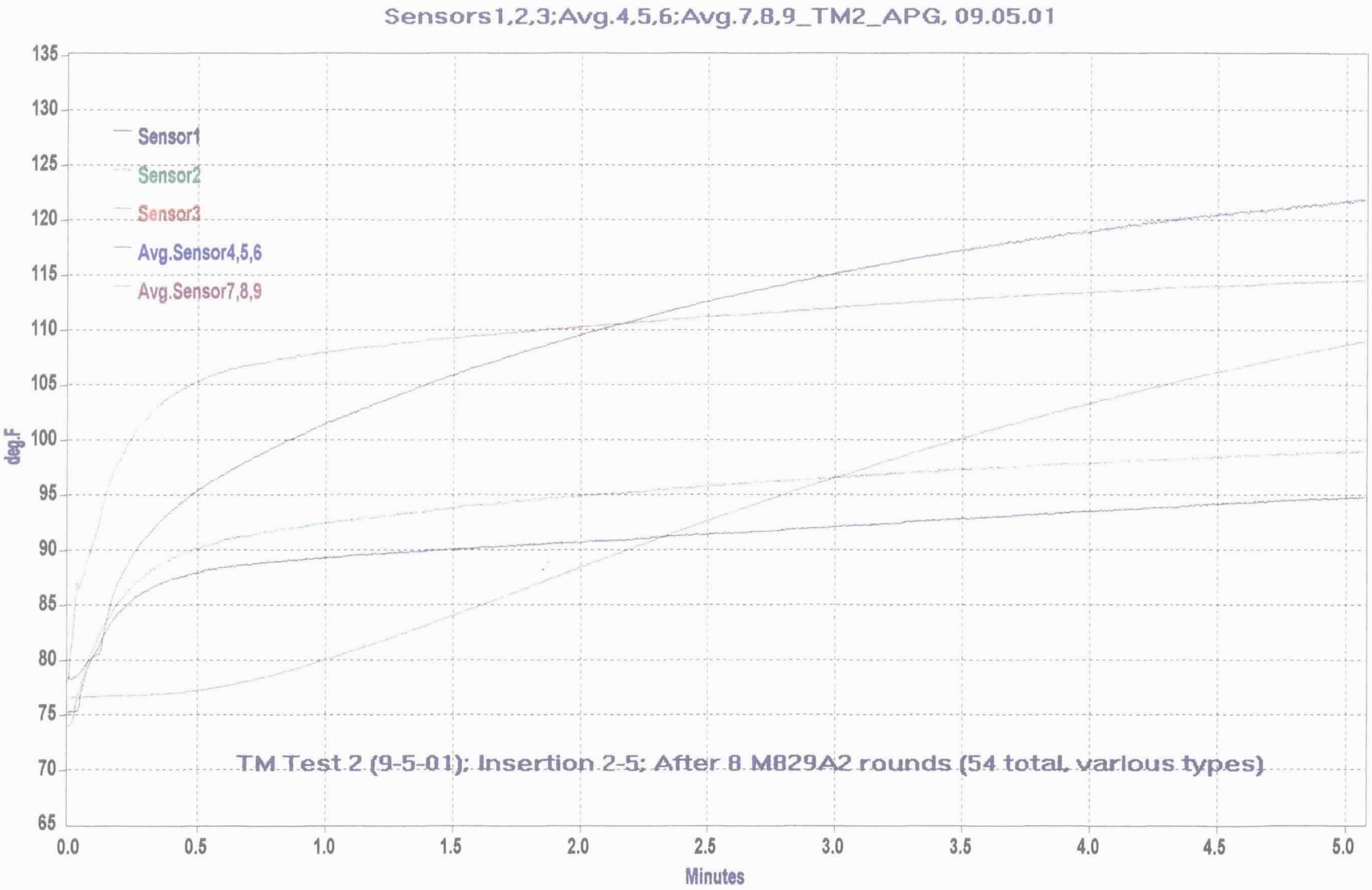

Figure 29
TM test 2, insertion 2-5 (8 M829A2 rounds; total 54 various types)

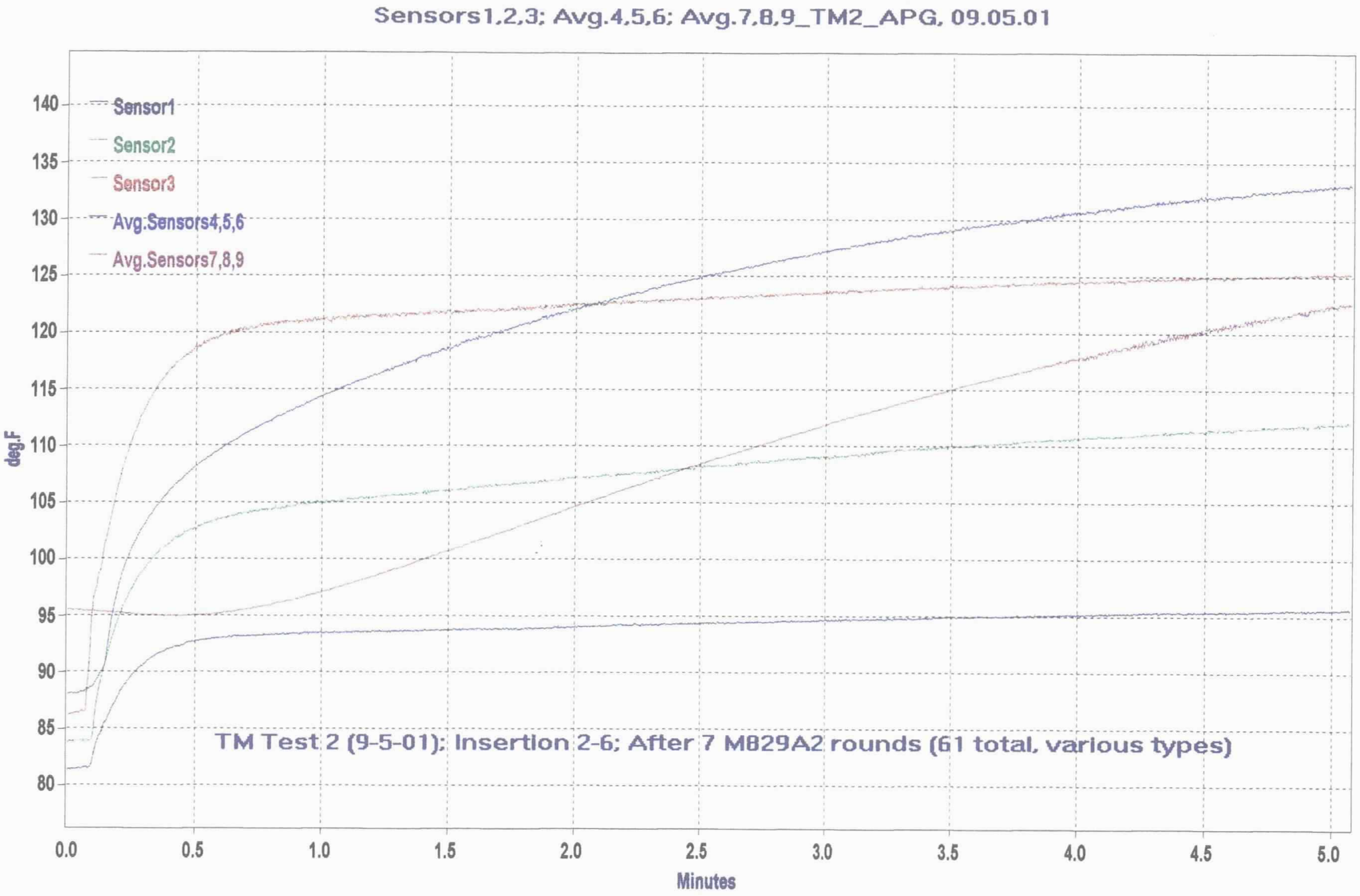

Figure 30
TM test 2, insertion 2-6 (7 M829A2 rounds; total 61 various types)

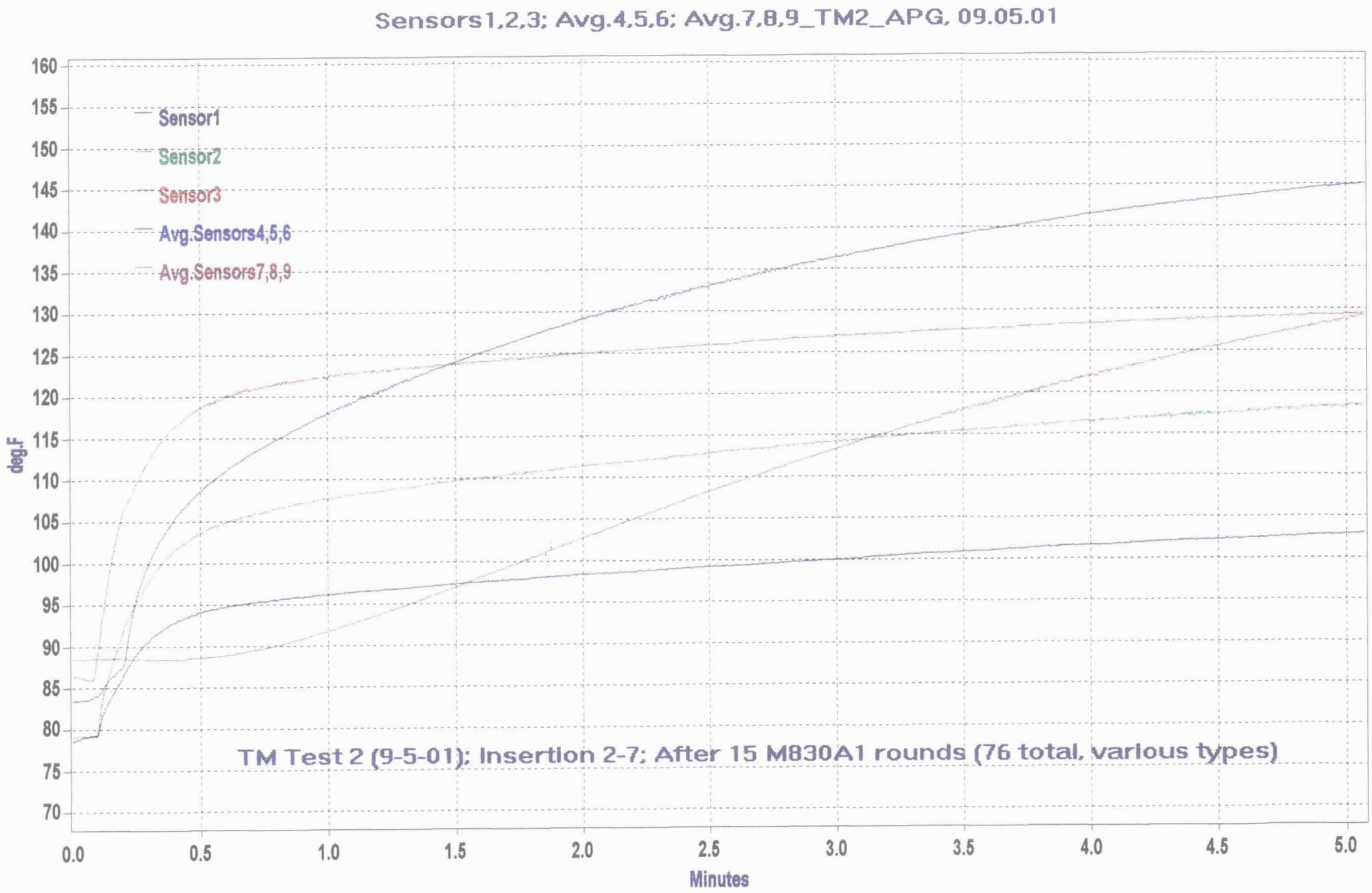

Figure 31
TM test 2, insertion 2-7 (15 M830A1 rounds; total 76 various types)

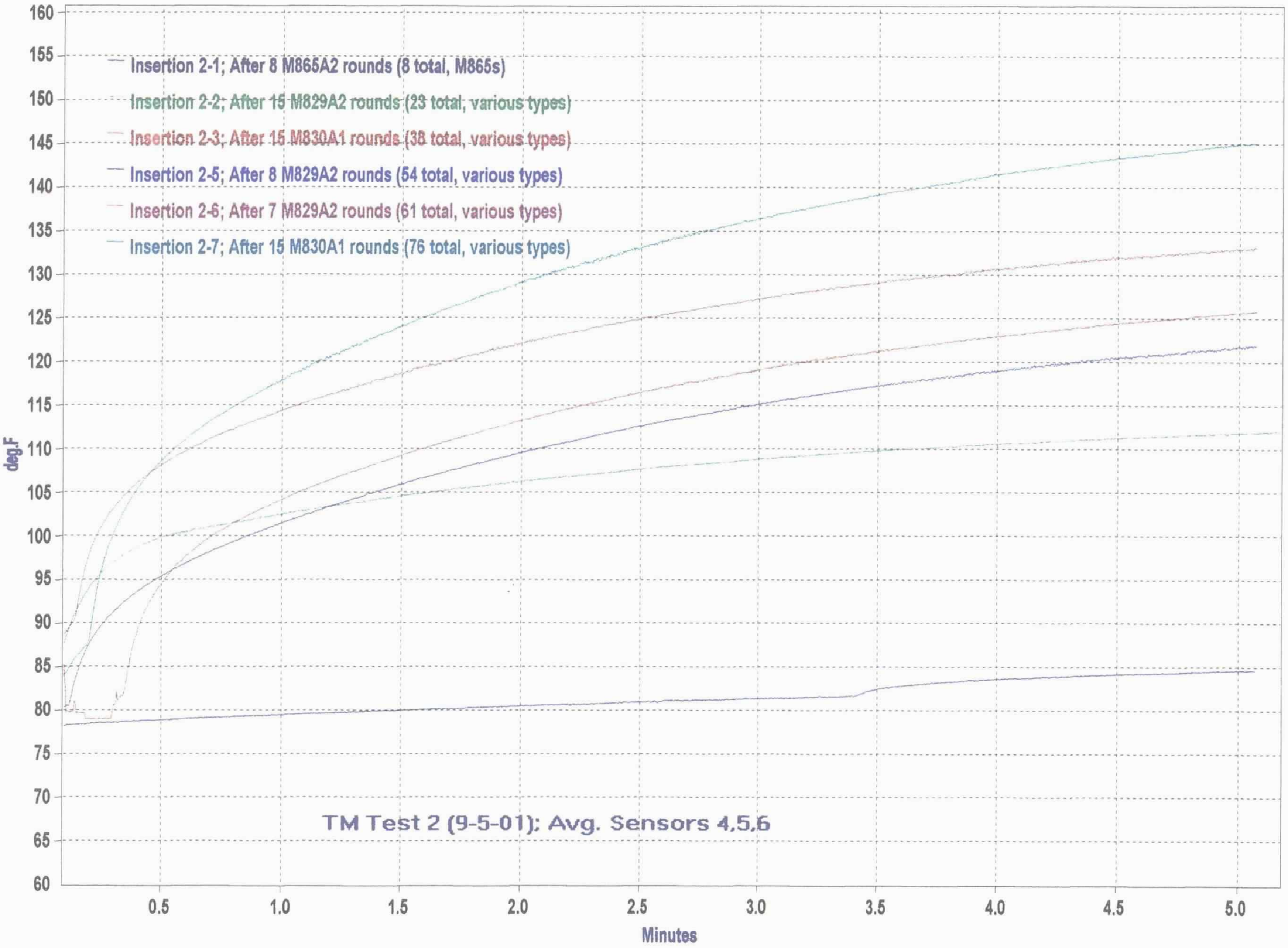

Figure 32
TM test 2, average temperature for sensors 4, 5, 6 (insertions 2-1 through 2-7)

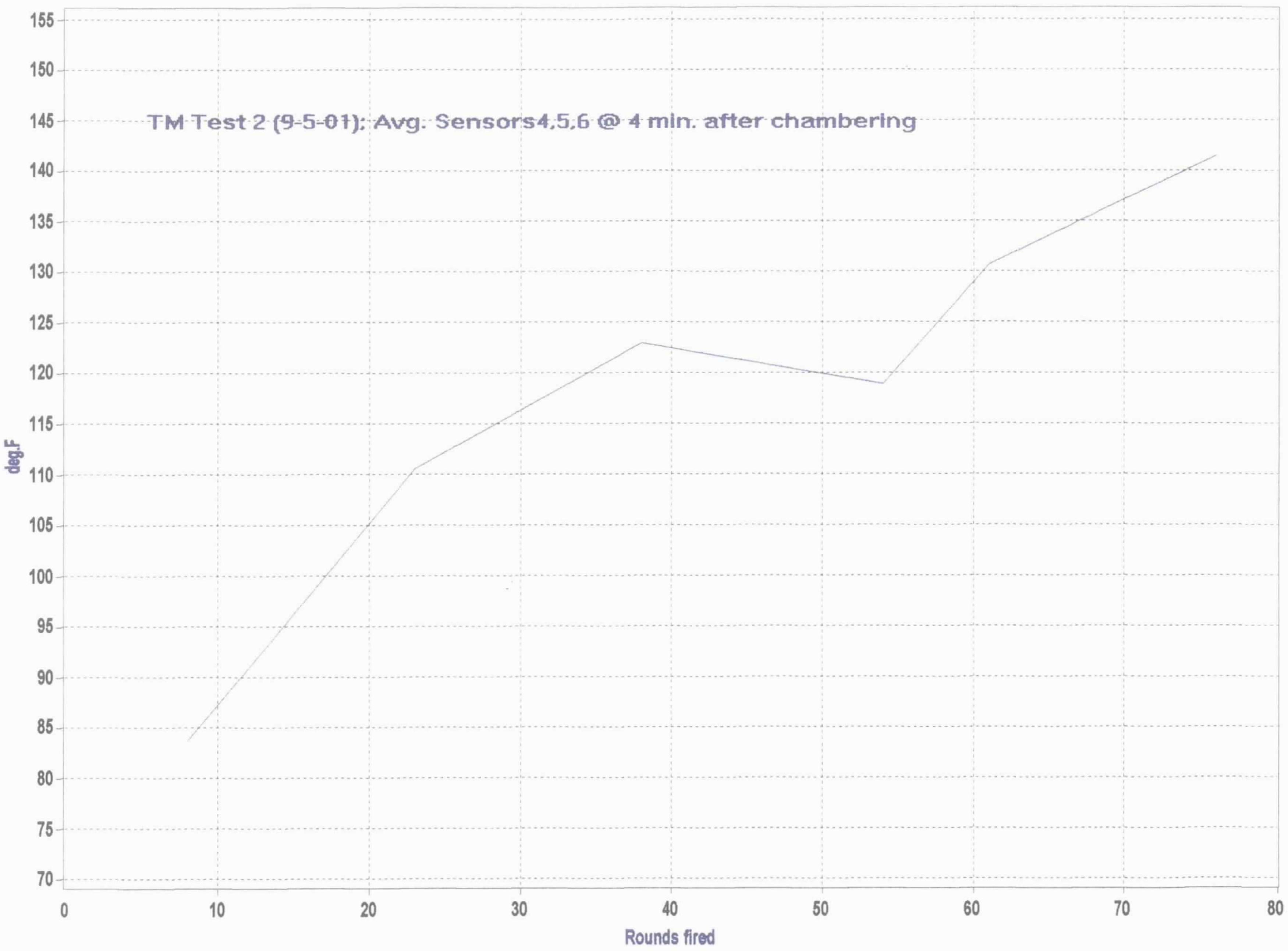

Figure 33
TM test 2, average temperature for sensors 4, 5, 6 at 4 min after chambering

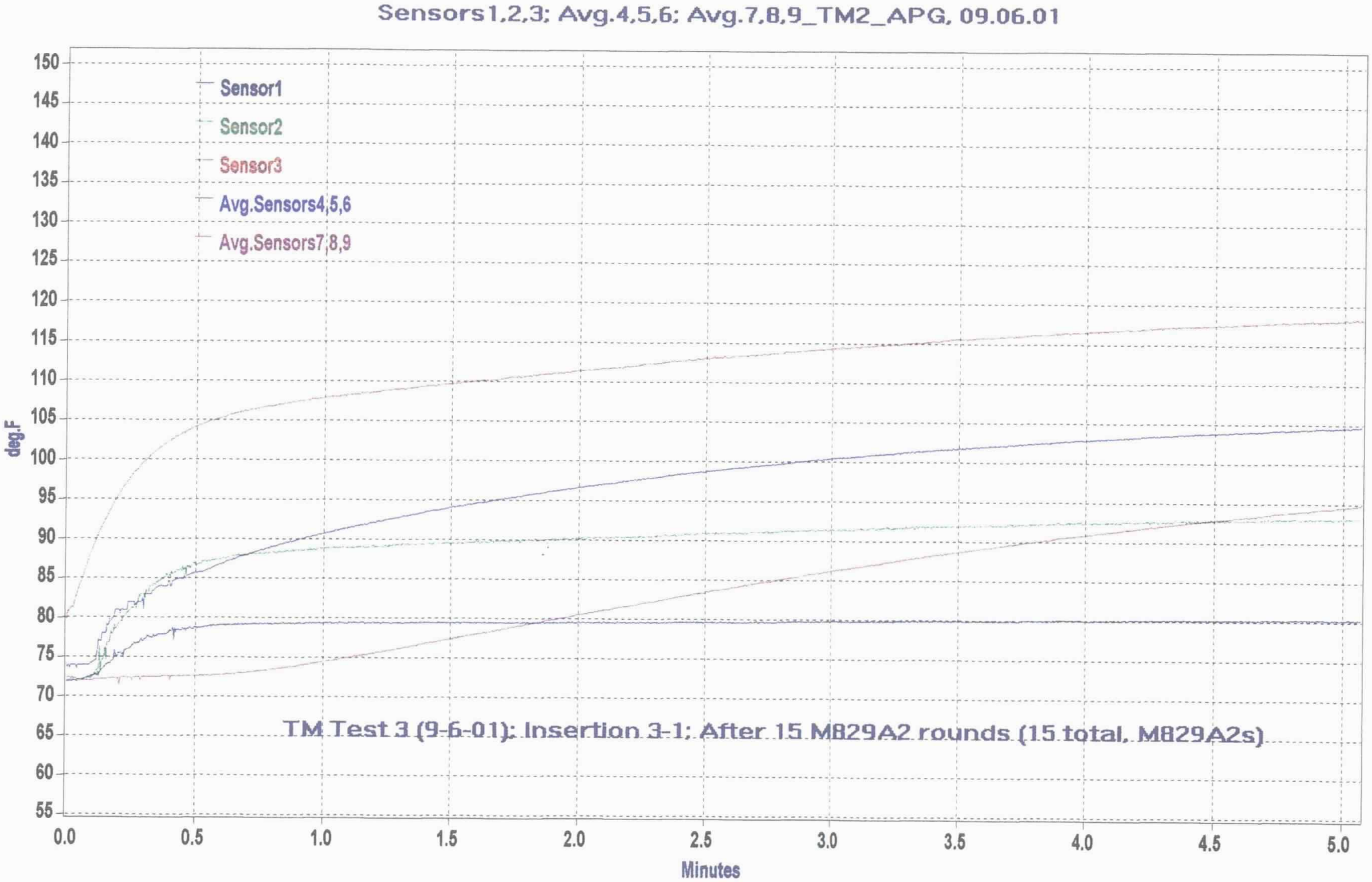

Figure 34
TM test 3, insertion 3-1 (15 M829A2 rounds)

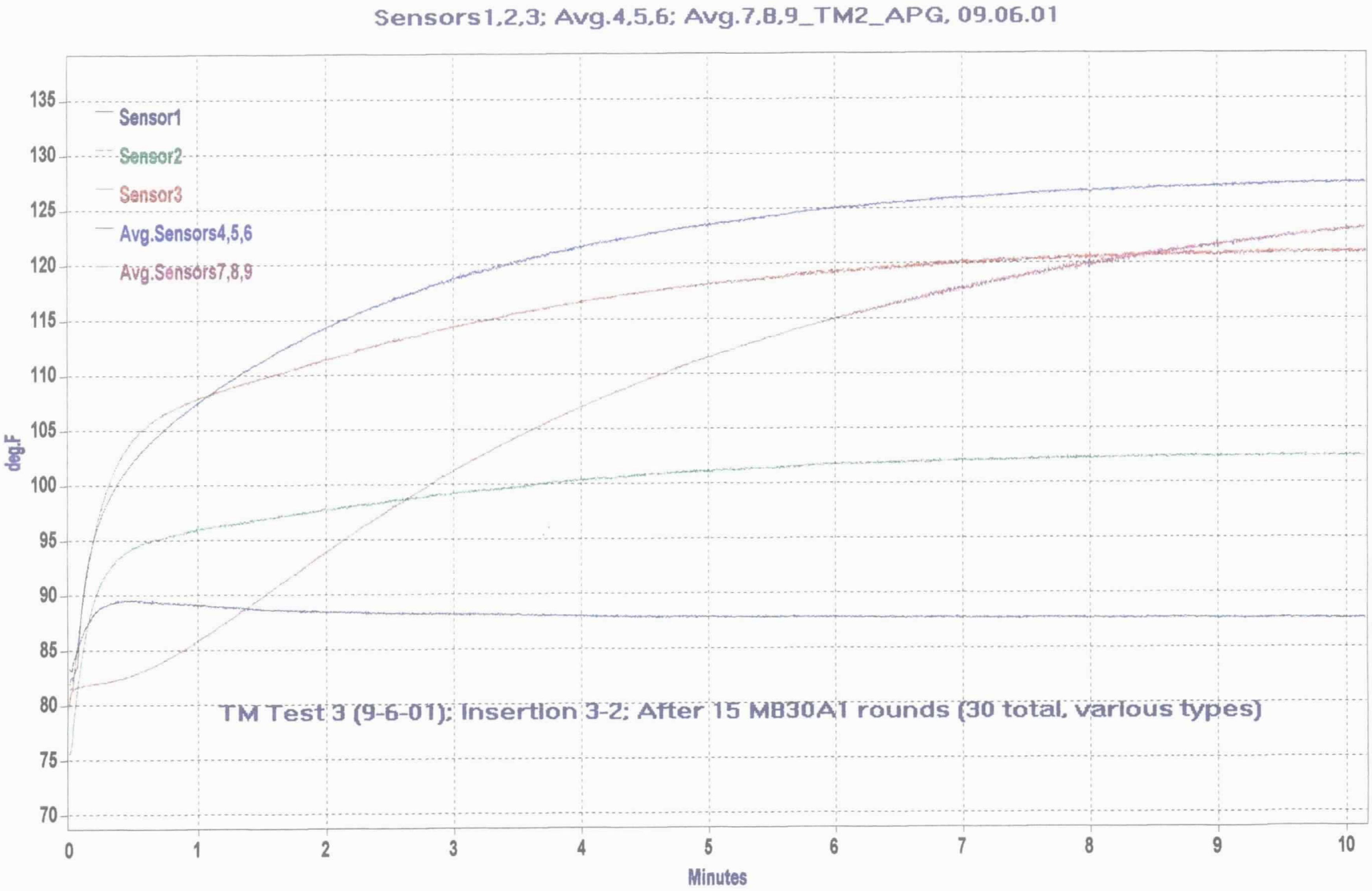

Figure 35
TM test 3, insertion 3-2 (15 M830A1 rounds; total 30 various types)

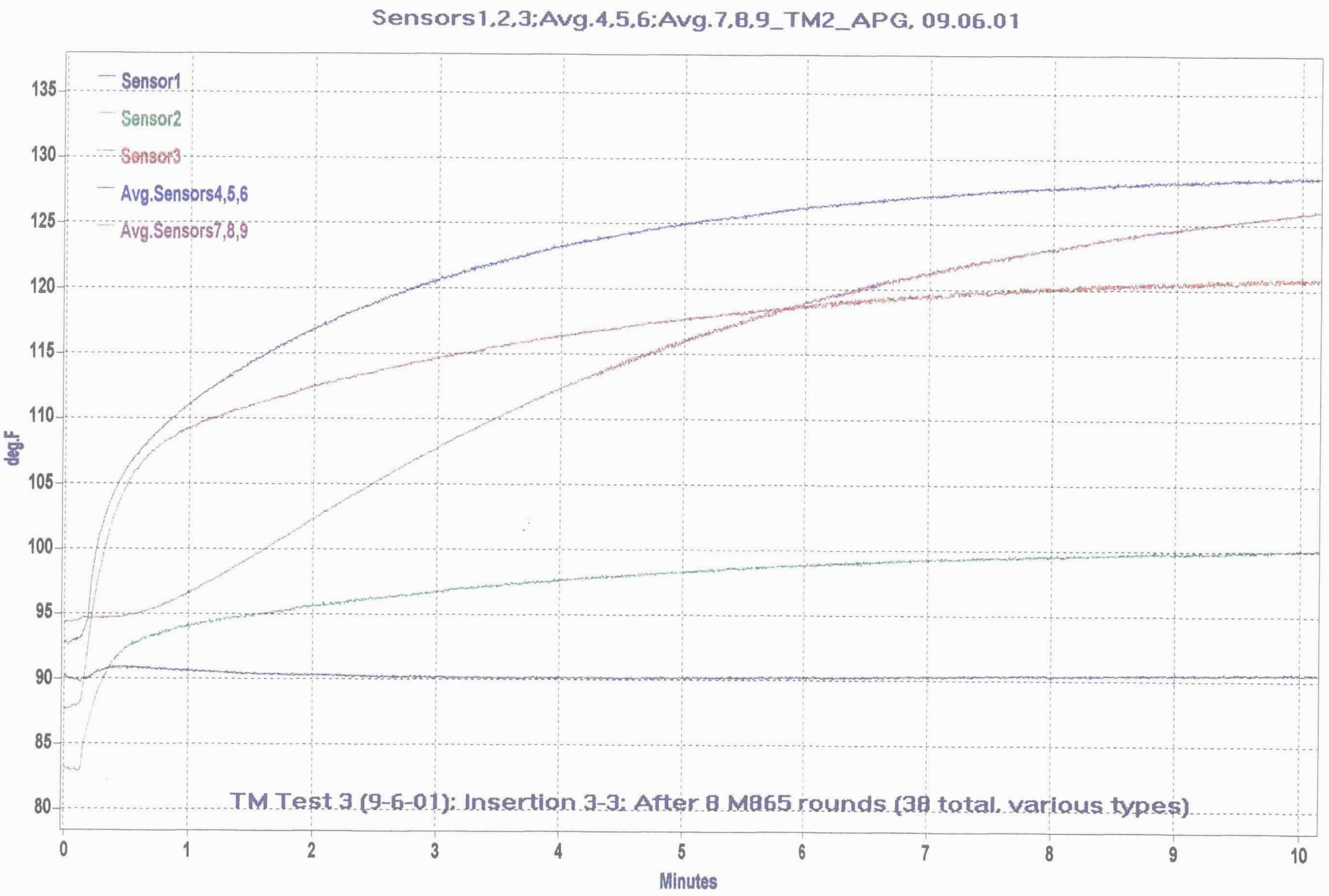

Figure 36
TM test 3, insertion 3-3 (8 M865 rounds; total 38 various types)

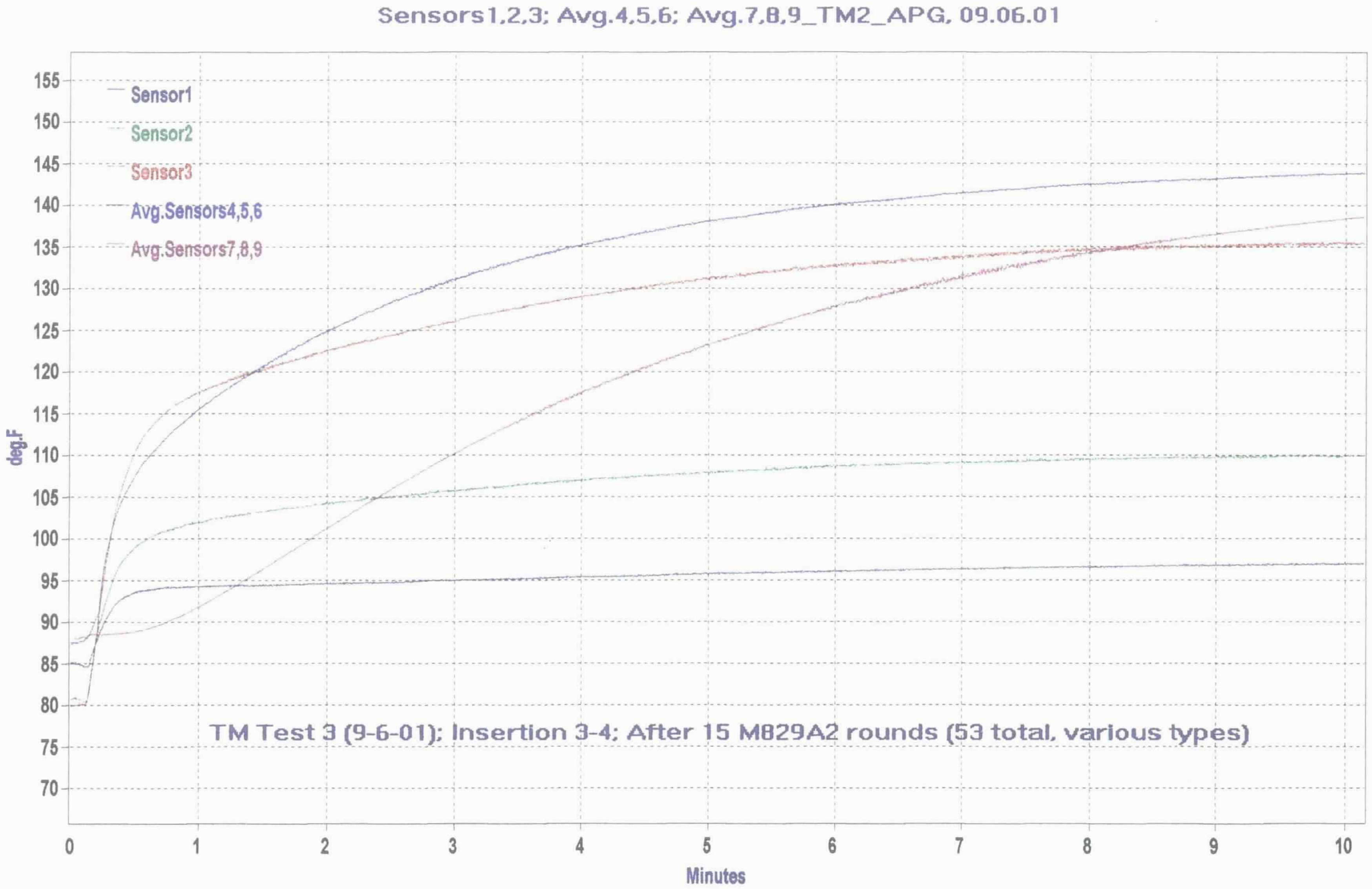

Figure 37
TM test 3, insertion 3-4 (15 M829A2 rounds; total 53 various types)

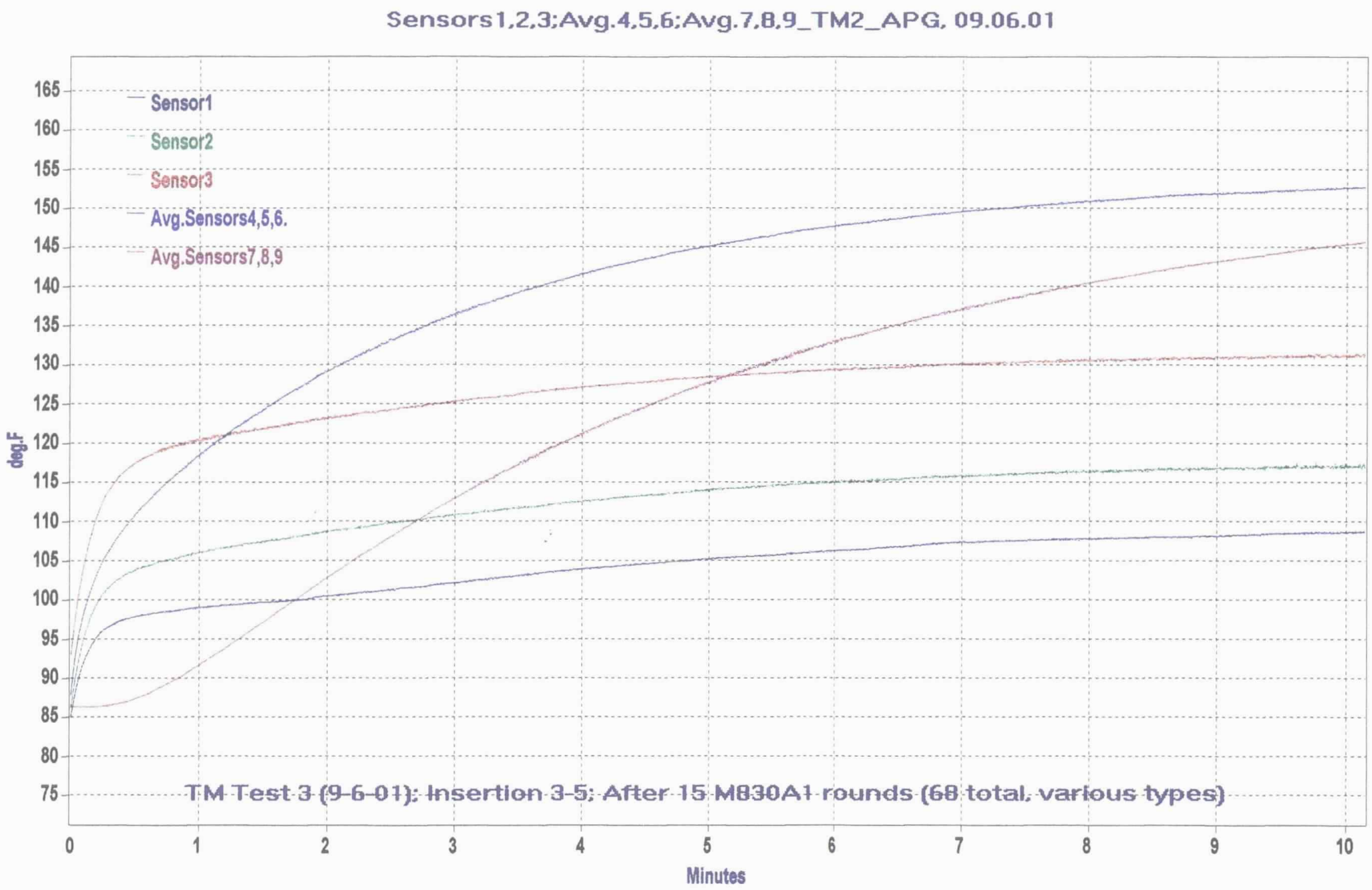

Figure 38
TM test 3, insertion 3-5 (15 M830A1 rounds; total 68 various types

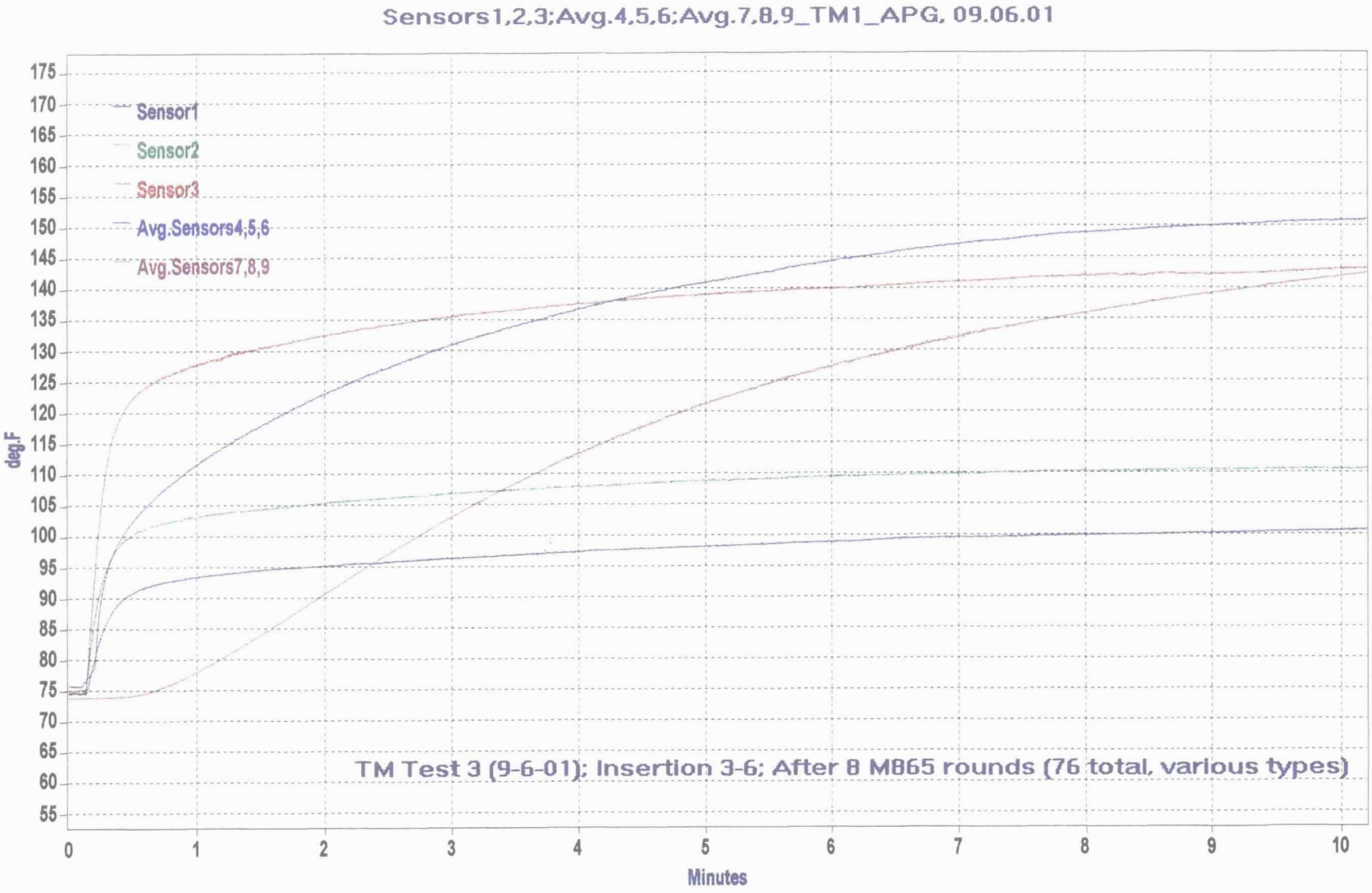

Figure 39
TM test 3, insertion 3-6 (8 M865 rounds; total 76 various types)

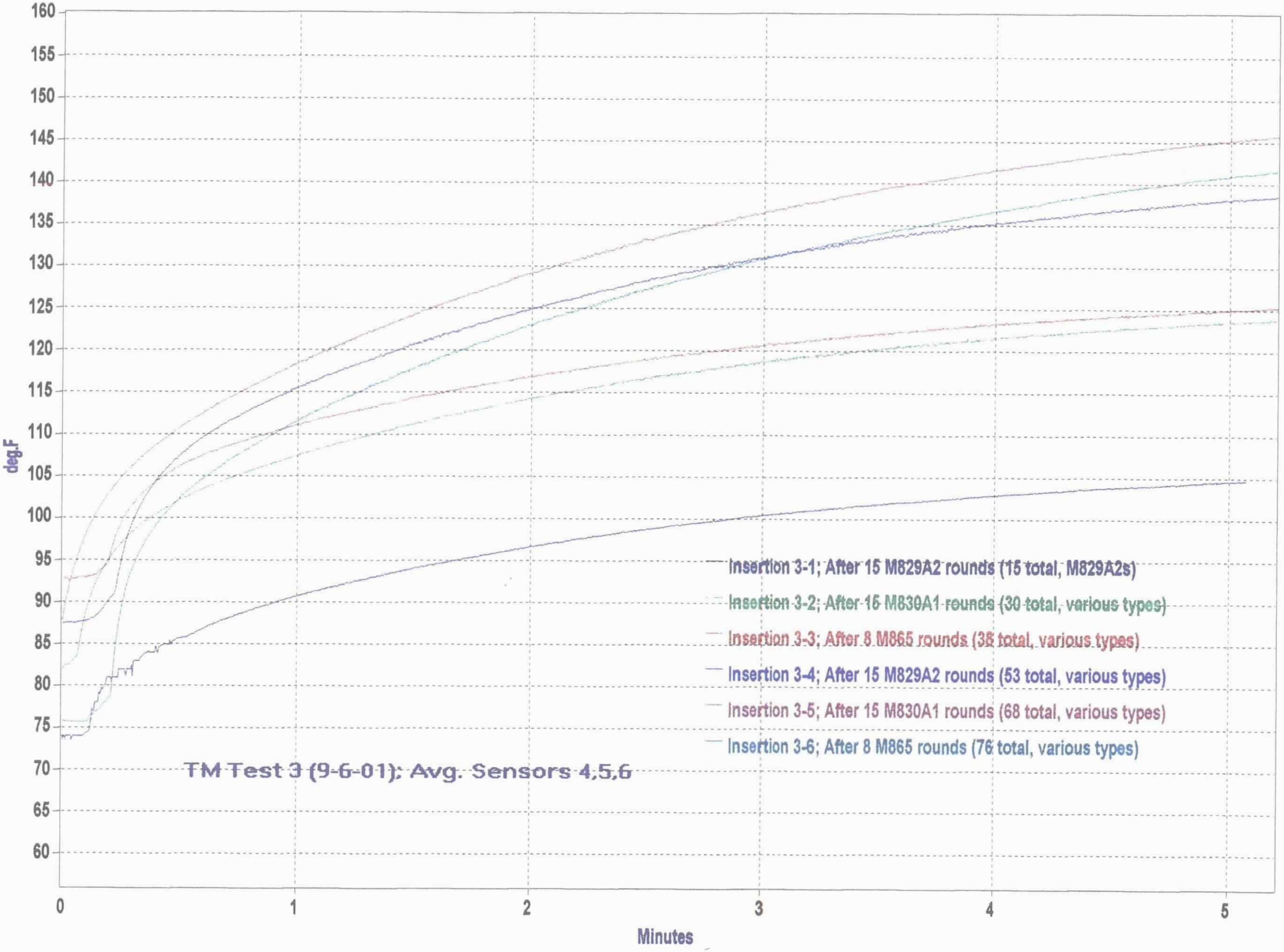

Figure 40
TM test 3, average temperature for sensors 4, 5, 6 (insertions 3-1 through 3-6)

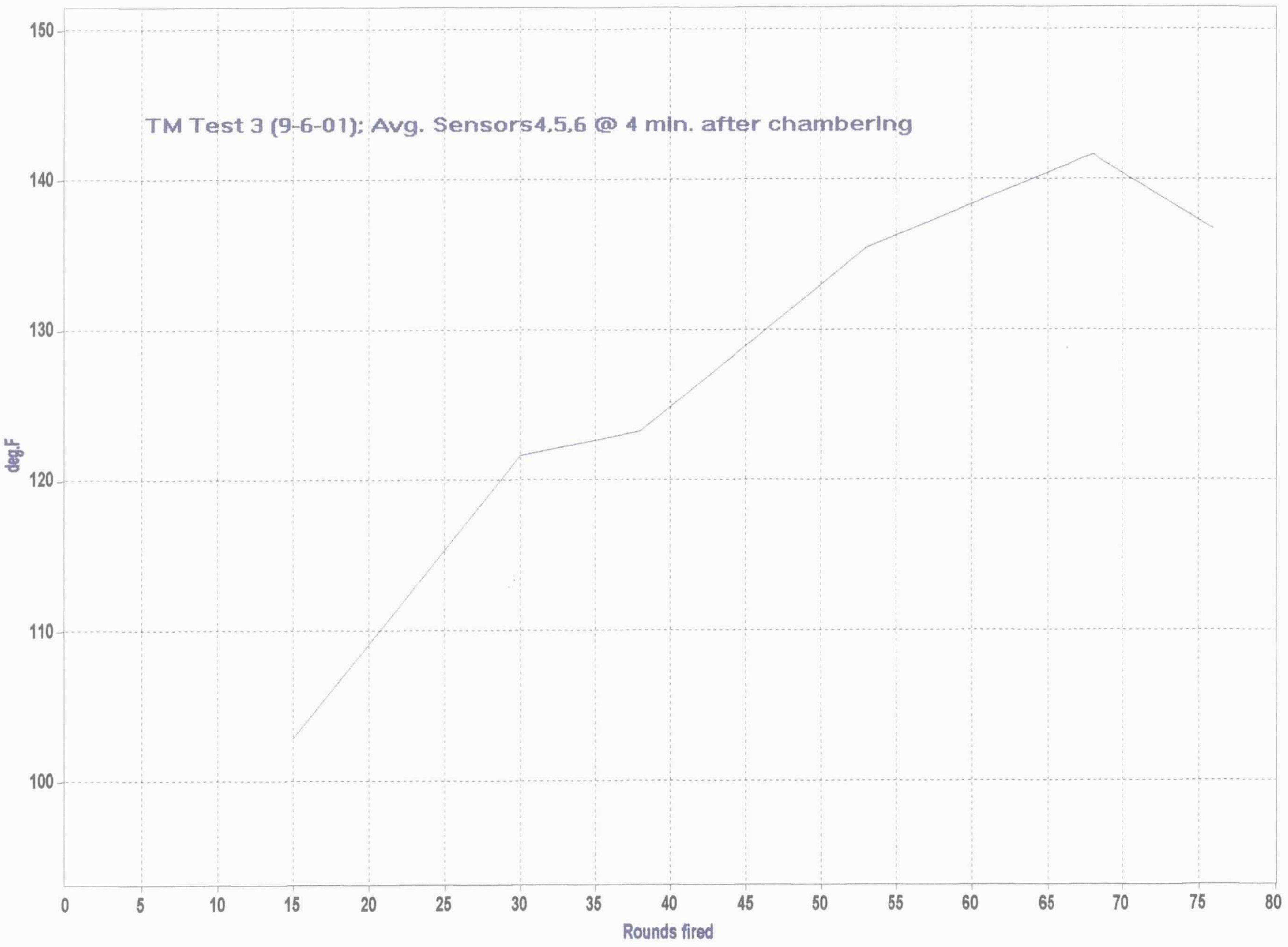

Figure 41
TM test 3, average temperature for sensors 4, 5, 6 at 4 min after chambering

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