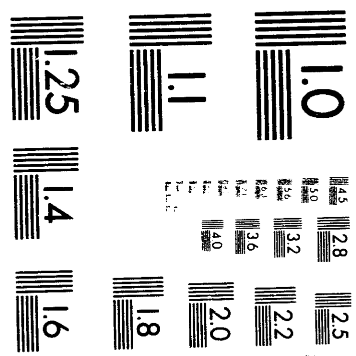

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Fire Tests to Evaluate the Potential Fire Threat and its Effect on HEPA Filter Integrity in Cell Ventilation at the Oak Ridge National Laboratory Building 7920

By

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SUMMARY

As a result of a DOE (Tiger Team) Technical Safety Appraisal (November 1990) of the Radiochemical Engineering Development Center (REDC), ORNL Building 7920, a number of fire protection concerns [see Attachment 1], were identified. The primary concern was the perceived loss of ventilation system containment due to the thermal destruction and/or breaching of the prefilters and/or high-efficiency particulate air filters (HEPA 's) and the resultant radioactive release to the external environment. The following report describes the results of an extensive fire test program performed by the Fire Research Discipline (FRD) of the Special Projects Division of Lawrence Livermore National Lab (LLNL) and funded by ORNL to address these concerns.

Full scale mock-ups of a REDC hot cell tank pit, adjacent cubicle pit, and associated ventilation system were constructed at LLNL and 13 fire experiments were conducted to specifically answer the questions raised by the Tiger Team. Our primary test plan was to characterize the burning of a catastrophic solvent spill (kerosene) of 40 liters and its effect on the containment ventilation system prefilters and HEPA filters. In conjunction with ORNL and Lockwood Greene we developed a test matrix that assessed the fire performance of the prefilters and HEPA filters; evaluated the fire response of the fiber reinforced plastic (FRP) epoxy ventilation duct work; the response and effectiveness of the fire protection system, the effect of fire in a cubicle on the vessel off-gas (VOG) elbow, and other fire safety questions. Because these were full scale fire tests conducted in full scale mock ups of REDC tank pits, cells, and cubicles, the results are as realistic as can be practically achieved without actually setting fire to the facility. All tests were set up and conducted conservatively. Although we were able to reproduce the ventilation rate through the tank pit and cubicle cell, our main exhaust provided less than half the dilution air provided in the actual facility. Therefore, the containment ventilation system filters were exposed to approximately twice the thermal and smoke assault it would experience in an actual fire situation. In addition, our filter system only provided half the number of filters than the actual system. This fact makes the results even more reasonable.

We were able to make the following conclusions from the results of the test program:

1. A fire in a tank pit of the ORNL REDC Bldg. 7920 would not cause the loss of ventilation system containment due to the thermal destruction and/or breaching of the prefilters and HEPA filters. All fire tests demonstrated that there was no danger of the prefilters or HEPA's failing thermally. Uninterrupted fires extinguished from lack of oxygen at all three tank pit ventilation rates. At the three airflow's of 1000, 440, and 370 cfm, a 40 liter kerosene fire could not exist for more than a few minutes. Although they were rough measurements, in the majority of tests, less than 10 liters of kerosene was able to burn or evaporate from the post fire heat. Even if it were possible, a fire from a larger kerosene spill would not cause the breaching of the prefilters and HEPA filters. In fact, due to the air flow pattern and quantity, a larger pool size would produce a larger fire that would deplete the oxygen at a more rapid rate and, consequently, burn for a shorter period of time.

2. The prefilters and HEPA filters remained in service for multiple tests with excellent residual filtering capabilities. This performance was certified by LLNL Industrial Hygienists who performed DOP filter penetration tests before and after each test. Results of all these tests were 0.01% penetration. Both sets of filters had been exposed to multiple kerosene fires, multiple fires with sprinkler spray, and an epoxy panel burn. These results are significant because they show that the actual roughing and HEPA filters could be left in service for an extended period of time after a fire event in a tank pit.

3. The VOG duct work will not ignite nor contribute to a tank pit fire. Under a number of worst case scenarios the duct did not ignite nor suffer any thermal damage, even though it was installed per Cell 3 specifications (positioning a horizontal run 3.5' above the fire along with vertical and other horizontal sections) and was exposed to 5 tank pit fire tests.

4. A kerosene fueled fire in a cubicle would have no effect on the VOG FRP ventilation duct . The gas burner tests that placed a flame directly into the FRP elbow demonstrated that the interior of the VOG duct, even without the asbestos liner, would not ignite and contribute to the fire. The fire threat to the elbow is very low because of the small size of the kerosene fire, but more importantly, the low ventilation rate in the cubicle. This lack of ventilation flow causes the fire to not only extinguish in a short time, but it also cannot attain a high level of intensity. Post test inspection showed that there was no thermal damage to the elbow. This gas burner exposure was more severe than a fire fueled by sparse quantities of polyethylene tubing, rags, and rubber gloves that could be resident within the cubicles.

5. Shutting off the inlet airflow to the tank pit almost immediately (within 1 minute) extinguished the fire: even at the 1000 cfm flow rate. This action would be a very effective fire suppression technique in the actual facility tank pits and cells.

6. Although the epoxy wall coating test was extremely unrealistic and severe, it demonstrated that even if the material could burn, it would have little or no thermal or smoke effect on the prefilters and HEPA filters. Thirty liters of kerosene and parts of the Wonder-Board burned during this experiment. Although the epoxy coating did not burn, some of the binder in the finish was driven off by the heat of the fire. In the actual facility, it is questionable whether there would be any effect on the epoxy coating. As it turned out, the Wonder Board itself ignited and contributed to the fire. Most of the burning took place from the back of the panels. An airflow pattern developed that ran down the wall and behind the very narrow space between the panels and the gypsum wallboard. Although we were not able to obtain an accurate weight measurement, our physical inspection of the panels after the test indicated that none of the polyamide cured epoxy burned and contributed to the fire. However, it appeared that some of the binder had been driven off by the heat in the areas where the epoxy coating was exposed directly to flame. As shown in Photo 38 the 30 mil coating is still intact, it just felt a little more brittle than in its virgin state. Also, post test inspection showed that approximately 50% of the panel area was affected by this heating. More significantly, it appears that combustible additives and the fiberglass mat in the Wonder Board ignited and continued to burn. From visual observations during the test, these additives appeared to be the fuel for flames shooting out from behind the panels for the duration of the fire. As mentioned earlier in the actual REDC tank pits and cells the epoxy coating was applied directly to the heavy, noncombustible concrete walls.

7. The fire detection and suppression system would respond quickly and efficiently. The heat actuated detectors (HADs) responded quickly and the sprinkler head knocked the fire down almost instantaneously. Sprinkler water vapor had no effect on the prefilters or HEPA filters. Because these fires could be extinguished by oxygen starvation, the sprinkler system could be used as a secondary means of suppression.

INTRODUCTION AND BACKGROUND

As a result of a DOE Tiger Team audit of the Radiochemical Engineering Development Center, ORNL Building 7920, a number of fire protection concerns were identified. These concerns focused on whether the fire detection and suppression systems would operate as designed and mitigate the maximum credible fire scenario within the hot cells and cubicles of the facility. Although not specifically called out in their report, the primary fire event was postulated to be fueled by flammable solvents and the burning of the VOG ventilation ducting within the hot cells. The primary concern was the perceived loss of ventilation system containment due to the thermal destruction and/or breaching of the prefilters (roughing) and HEPA filters and the resultant radioactive release into the outside environment.

Although a detailed analytical study [1] in 1987 found that a fire would not damage the HEPA filters, the Tiger Team concluded that the report used "questionable and potentially non conservative assumptions to reach the conclusion that a fire would not result in an unacceptable release." Consequently, REDC management made the decision to fund a full-scale fire test program to directly address the concerns and findings of the audit. Due to our previous involvement and our extensive experience with the fire and smoke response of HEPA filters, the Fire Research Discipline (FRD) of Lawrence Livermore National Laboratory (LLNL) was asked to participate in the design and performance of this test program. The main objective of the study was to obtain hard data to answer the concern raised by the Tiger Team (FP.3-2) (H1/C1) CAT. II: "Documentation provided by Oak Ridge National Laboratory and DOE Headquarters does not support the conclusions that a fire originating in the cells or cubicles of Bldg. 7920 at the Oak Ridge National Laboratory would not result in the loss of HEPA filters and an unacceptable radiological release to the environment." [Attachment 1]. In order to achieve this objective a number of significant questions had to be answered:

1. In a worst case situation, at what intensity and duration will a solvent-fueled fire burn? Qualitatively, what quantity of smoke is generated and what are its characteristics?

2. Considering the actual location of the vessel off-gas (VOG) ducting, will it ignite from the effects of the kerosene fire?

3. Will the VOG duct stop burning if the source fire is removed?

4. How well will the VOG duct (duct elbow) endure a simulated cubicle fire?

5. What effect will the heat and smoke produced by the burning solvent and/or burning duct have on the prefilter and HEPA filter array?

6. Will the fire become oxygen (O_2) limited and eventually go out?

7. Will the addition of water from fire sprinklers increase the challenge of the prefilters and HEPA's?

8. What is the temperature drop of the combustion gases from the test fire to the prefilters and HEPA's?

Both the FRD and ORNL determined that the only way to obtain conclusive results and to accurately analyze the fire performance of the ventilation system, fire protection system, prefilters/HEPA filter array, FRP VOG duct, etc. was to design and conduct a full scale fire test series. In order to design and construct a representative test article, we had to gain an accurate and detailed understanding of the actual facility layout, fire protection systems, facility operating procedures, and ventilation system and operation. FRD personnel toured Bldg. 7920 to obtain first hand insight into its configuration and operational parameters. However, since most of the significant areas were inaccessible, we spent a significant amount of time studying photos, building plans, facility SAR, and talking to knowledgeable people. Through numerous phone calls and facsimile transmissions to ORNL and Lockwood Greene, we were able to complete these tasks and began developing a detailed test design. The majority of our questions were answered and information provided by personnel from Lockwood Greene. Although general information was available from other sources, detail and historic questions were answered by Lockwood Greene. In fact, Lockwood Greene provided a great deal of help in developing the preliminary fire test matrix included as Table 4.

BUILDING 7920 FACILITY DESCRIPTION

As it turned out, NJ Alvares in his report [1] provided a good general facility description summary. It is, therefore, presented below:

Facility Specifications

"Figure N-1 is a plan view of the transuranium processing plant showing both office and operator's areas, and an isometric drawing of a typical cell in the operations area of the building. The shielded cell bank contains nine 7 ft. wide hot cells each with a 7 ft. long cubicle area, separated from each other by 2.0 ft. minimum thick concrete walls. Seven cells contain a tank pit area (9 x 22 ft. high). An inter-cell conveyor housing and the cell-ventilation exhaust duct run through the cubicle pits the full length of the cell bank.

"In the first seven cells air enters the south wall of the tank pit through a duct (10 in. diameter), the centerline of which is 21 ft. above the floor. The air exits the north wall of the tank pit to the cubicle pit through a slot (2 x 4 ft.) ten feet above the cell floor and is drawn into a cell ventilation duct (20 x 40 in.) through an opening (17.5 in. diameter) located 8.5 ft. above the cell floor.

"In the last two cells air enters the cubicle pit through a similar duct only 2' above the pit floor and exits to a cell ventilation duct. A waste-tank pit behind the last two cells and below the first-floor level is connected to each of the last two cubicle pits through a 2 ft square opening, but there is no air inlet to the waste pit and essentially no air flow between the waste tank pit and the last two cubicle pits.

"The air from all of the cells exits the cell ventilation duct through a 40 x 18 in. opening in the bottom of the duct in the Cell 5 cubicle pit and passes under the cell through a 37 ft. long, 30 in. diameter duct to the cell off-gas (COG) filter inlet plenum located within the building south of the cell bank.

"The volume of each tank pit is 1386 $ft.^3$ and the air supply to each is approximately 440 cfm."

Ventilation

"The off-gas systems ventilate components of the cell--the tanks, the cubicle, the cubicle pit, and the tank pit. Note that the tank and cubicle pits are served by COG ventilation with metal conduits. The vessel off-gas (VOG) header that collects effluent from the tanks is metal; the header that collects effluent from the cubicles is fiber-reinforced plastic (FRP). Because off-gases from the cubicles and tanks may contain hazardous materials, they are always passed through a caustic scrubber and possibly through carbon bed adsorbers.

"... The ventilation path comes in high and exits the tank pit through the access opening into the cubicle pit. In the cubicle pit a large metal duct collects this air and conveys it to an exhaust duct under the fifth cubicle where total flow is directed to the HEPA filter system before exiting through the stack. Inlet air is ducted high near the tank pit ceiling, and the air exit is at the half-height level into the cubicle pit. Total air flow through individual pit systems is approximately 440 cfm during normal operations."

PROJECT PLAN

A significant part of the project was to construct a test article which reproduced an actual Bldg. 7920 tank pit and cubicle pit in terms of size and configuration. An even more important part of the project was to reproduce the relevant parts of the containment ventilation system, not only in terms of ventilation components but also for normal and unique operating conditions. In addition, the fire protection system had to be simulated and installed. Furthermore, operational procedures had to be identified to define potential fire scenarios to be used to address the Tiger Team concerns. Our basic philosophy was to use the most severe credible scenario based on actual fact and be conservative for worst case situations, but not be ridiculously unrealistic. In general terms, the project plan identified the following areas to be studied:

1. The fire characteristics produced by a maximum credible solvent spill in both quantity and configuration.

2. The effect on the fire of varying the airflow rate, based on actual operational procedures.

3. The effect of turning off the cell airflow completely.

4. The response of the fire detectors and the effectiveness of the sprinkler system on extinguishing the fire.

5. The response of the filter system to the sprinkler water vapor and combustion products.

6. Ignitability and fire performance (thermal and smoke production) of the VOG duct in the Cell 3 tank pit.

7. Characterize the fire performance of the 30 mil epoxy coating on the pit concrete walls.

8. Characterize a cubicle fire and assess the ignitability and flame spread of the interior of a VOG ventilation duct elbow.

In order to define the fire risk to the REDC facility, the fire threat and the performance of the containment ventilation system had to be assessed. In reality, to determine the fire risk the probability of ignition would have to be taken into account. However, to evaluate the above characteristics, we assumed that the probability of ignition was 100%. Late in the test program we addressed the potential for kerosene ignition by electrical overload failures.

SOLVENT (KEROSENE) FIRE EXPERIMENTS

A significant phase of the study was to characterize the fire and smoke characteristics of a representative flammable solvent in realistic cell fire scenarios. From studying the flammability characteristics of the various solvents used in the TRU processes, it was decided that kerosene provided the most severe fire and smoke assault. It was also determined (through operational procedures, etc.) that the maximum possible spill in a tank pit would be 40 liters.

VOG DUCT FLAMMABILITY

Another Tiger Team concern was the potential for the ignition of the VOG duct in the tank pit and its subsequent contribution to the smoke loading of the filtration system. As mentioned previously, these ducts were of the same formulation as the actual Bondstrand ducts but did not have the asbestos inner liner. Our tests would place the duct in the most conservative position according to Cell 3 specifications. In this cell a horizontal section as shown in Figure

3 is only 3.5' from the floor. The duct would experience the most severe tank pit fire exposure in this orientation.

CUBICLE FIRE SIMULATION

The tests of the VOG duct addressed the fire response of the material from a fire source impinging on the duct's exterior and the resultant fire spread on the exterior of the duct. A fire in one of the cubicles would cause heat, flame, and smoke to be pulled into the FRP pipe and would challenge its interior. Depending on the severity of the cubicle fire, the interior flame spread could be much more severe than external fire spread. Because the exemplar ducts do not contain an asbestos interior lining, this test would be very conservative.

The simulated cubicle for this phase was built inside the tank pit mock up with the VOG elbow coming out of the ceiling with the specified airflow pulled through it. We characterized the probable cubicle fire.

EPOXY PANEL TEST

The Building 7920 pit surfaces (except the floor) are covered with a 30-mil layer of FRP laminate which is described in Table 3. We felt that because this coating was so thin and laminated to heavy concrete surfaces, the heat loss to the concrete would prevent the ignition of the FRP. However, we conducted a test with a thin cementitious substrate to evaluate the hypothesis.

TEST STRUCTURE

Both the FRD and ORNL determined that the only way to obtain conclusive results and to accurately analyze the fire performance of the ventilation system, fire protection system, prefilters/HEPA filter array, FRP VOG duct, etc. was to construct the full scale test article. In order to realistically assess the performance of the ventilation system under the postulated fire conditions, we wanted to simulate as near as possible a full-scale mock-up of a hot cell. The test article is shown graphically in Figures 1 through 5 and pictorially in Photos 1 through 4. The structure was a full-scale representation with the tank pit height at 22'. Note that the cubicle is not reproduced (it would be located where the enclosure steps down) because it plays no part in this phase of testing. The outline (shown in Figures 1-4) define where the cubicle would sit in the actual facility. The duct leading from the cubicle pit area had several bends and resulted in a total run of approximately 45' from the pit to the HEPA filter bank. This mock-up was modeled after cell #3 in terms of dimensions, ventilation layout, etc. The test article was constructed as a 2"x4" stud frame construction (Photo 3) with an inner liner of plywood for shear strength. The interior was lined with 2 layers of 5/8" Type "X" fire rated gypsum wallboard (Photos 8 & 9). The 2 layers were staggered to eliminate through seams and each seam was caulked with a silicone sealant to prevent air leakage. The sump floor construction was constructed to duplicate that in the actual facility. The access doors (Photo 7) shown in the structure are to facilitate test set-up, etc. Viewing ports are included in the doors so that the fire(s) can be viewed and photographed until it becomes obscured by smoke. A hatch in the roof of the tank pit was also provided for global viewing within the enclosure. The actual REDC cells are monolithically cast concrete with 2.0' thick walls and containment requirements dictate no leaks.

Figure 3 displays the dimensions of the tank pit and the cell area that would be below the cubicle. In the actual facility, due to the configuration of the cubicle within the cell, a quantity of air leaks past the cubicle into the lower pit area. We have simulated this leakage airflow with the two 12" diameter snap ducts with 90^{o} bends (total cross sectional area: 226 in^{2}) as shown in Photo 3.

Not only did we strive to duplicate the dimensional and volumetric dimensions of the structure but also any openings between the cells as well as the sloped floor and sump in the tank pit. To ensure that we reproduced the multi angled slopes of the floor, we first installed a number of metal "ribs," shown in Photos 5 & 6 duplicating the sump contours, then we poured concrete to duplicate the tank pit floor and installed a drain pipe (with plug). The 2' by 4' opening (Photo 10) located approximately 10' from the floor was provided between the tank pit and the cubicle pit. All penetrations were sealed and the two exterior access doors were specially designed to form a positive seal when secured. Since three separate types of fire tests were conducted in the test article, several modifications were made as the project progressed.

VENTILATION SYSTEM

The ventilation system to the tank pit and cell were reproduced as closely as possible to the actual REDC system as shown in Figures 1 & 2. As can be seen in Figure 4 air enters what would be the east wall of the LLNL tank pit mock up through a 10 in. diameter duct, the centerline of which is approximately 21 ft. above the floor. The air exits the west wall of the tank pit to the cubicle pit through a slot (2 x 4 ft.) ten feet above the cell floor and is drawn into a cell ventilation duct (20 x 40 in.) through an opening (17.5 in. diameter) located 8.5 ft. above the cell floor. This configuration which is shown in Figure 4 produces a unique air flow. What is not shown is the transient swirling pattern the air takes at the floor level. As will be seen in the test results, the oxygen available to the sump floor is greatly reduced by this airflow pattern. For these tests, three flowrates of 1000, 440, and 370 cfm were supplied to the tank pit representing a high, normal, and low airflow respectively. Once the air exits the test article it enters the main ventilation duct with a total exit air flow of approximately 3600 cfm. This ventilation rate is approximately half of the 7310 cfm that is the actual flow rate in the REDC facility. This cuts the dilution rate down considerably in terms of heat dissipation as well as smoke dilution.

The detailed specifications for the roughing and HEPA filters are included in Table 3. The filter enclosures were two AstroSEAL housings each designed for filters stacked one wide and three high. As shown in Figure 1, the pre or roughing filters were stacked in this three high and one wide configuration. Behind them were three 1000 cfm HEPA's also stacked three high and one wide. Both the inlet and exit duct to the filter housing were round 18" diameter metal ducting with a baffle at the inlet side. This baffle was designed to distribute the incoming air fairly uniformly to the three roughing filters. The ventilation air was pulled through the system by the LLNL variable speed blower. The primary specifications for this fan include:

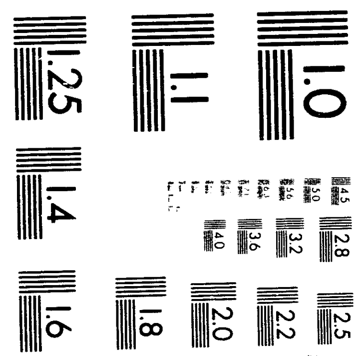
- Buffalo Forge, Size 7E, F.S.
- Flowrate : 3000 cfm
- Speed : 3550 RPM, 26.4 BHP
- Efficiency : 52.5%
- Wheel Diameter : 22.75 in.

Twelve 10' (nominal 8" I.D.) sections of VOG duct and two 90° (nominal 4" diameter) elbows are displayed in Photo 22. The 8" ducts were for the tank pit tests and the elbow was for the cubicle burns. These sections of duct were formulated to the original Bondstrand specifications shown in Table 3, but were not made by Bondstrand. Differences between these test samples and the actual REDC duct work is that our test ducts do not have the asbestos interior lining which would make the interior more fire resistive than the specimens fabricated for fire testing. It should be noted that these duct components were stored outside at LLNL, exposed to the elements for a number of months.

FIRE PROTECTION SYSTEM

The REDC cell and cubicle fire protection system consist of both fire detection and sprinklers. The system description as depicted in the SAR [2] is presented below:

> Each cubicle contains a thermopneumatic rate-of-rise device. Three rate-of-rise devices are located in each cell, one on top of the cubicles, one underneath the cubicle, and one near the top of the tank pit. The integrity of each system is monitored with a supervisory air signal which triggers an alarm in the event of failure. If any one of these devices in the cell bank detects a temperature rise of 8 to 11° C/min. (15° to 20° F/min.), the main header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5. Shutting off the inlet airflow to the tank pit almost immediately (within 1 minute) extinguished the fire: even at the 1000 cfm flow rate. This action would be a very effective fire suppression technique in the actual facility tank pits and cells.

6. Although the epoxy wall coating test was extremely unrealistic and severe, it demonstrated that even if the material could burn, it would have little or no thermal or smoke effect on the prefilters and HEPA filters. Thirty liters of kerosene and parts of the Wonder-Board burned during this experiment. Although the epoxy coating did not burn, some of the binder in the finish was driven off by the heat of the fire. In the actual facility, it is questionable whether there would be any effect on the epoxy coating. As it turned out, the Wonder Board itself ignited and contributed to the fire. Most of the burning took place from the back of the panels. An airflow pattern developed that ran down the wall and behind the very narrow space between the panels and the gypsum wallboard. Although we were not able to obtain an accurate weight measurement, our physical inspection of the panels after the test indicated that none of the polyamide cured epoxy burned and contributed to the fire. However, it appeared that some of the binder had been driven off by the heat in the areas where the epoxy coating was exposed directly to flame. As shown in Photo 38 the 30 mil coating is still intact, it just felt a little more brittle than in its virgin state. Also, post test inspection showed that approximately 50% of the panel area was affected by this heating. More significantly, it appears that combustible additives and the fiberglass mat in the Wonder Board ignited and continued to burn. From visual observations during the test, these additives appeared to be the fuel for flames shooting out from behind the panels for the duration of the fire. As mentioned earlier in the actual REDC tank pits and cells the epoxy coating was applied directly to the heavy, noncombustible concrete walls.

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INTRODUCTION AND BACKGROUND

As a result of a DOE Tiger Team audit of the Radiochemical Engineering Development Center, ORNL Building 7920, a number of fire protection concerns were identified. These concerns focused on whether the fire detection and suppression systems would operate as designed and mitigate the maximum credible fire scenario within the hot cells and cubicles of the facility. Although not specifically called out in their report, the primary fire event was postulated to be fueled by flammable solvents and the burning of the VOG ventilation ducting within the hot cells. The primary concern was the perceived loss of ventilation system containment due to the thermal destruction and/or breaching of the prefilters (roughing) and HEPA filters and the resultant radioactive release into the outside environment.

Although a detailed analytical study [1] in 1987 found that a fire would not damage the HEPA filters, the Tiger Team concluded that the report used "questionable and potentially non conservative assumptions to reach the conclusion that a fire would not result in an unacceptable release." Consequently, REDC management made the decision to fund a full-scale fire test program to directly address the concerns and findings of the audit. Due to our previous involvement and our extensive experience with the fire and smoke response of HEPA filters, the Fire Research Discipline (FRD) of Lawrence Livermore National Laboratory (LLNL) was asked to participate in the design and performance of this test program. The main objective of the study was to obtain hard data to answer the concern raised by the Tiger Team (FP.3-2) (H1/C1) CAT. II: "Documentation provided by Oak Ridge National Laboratory and DOE Headquarters does not support the conclusions that a fire originating in the cells or cubicles of Bldg. 7920 at the Oak Ridge National Laboratory would not result in the loss of HEPA filters and an unacceptable radiological release to the environment." [Attachment 1]. In order to achieve this objective a number of significant questions had to be answered:

1. In a worst case situation, at what intensity and duration will a solvent-fueled fire burn? Qualitatively, what quantity of smoke is generated and what are its characteristics?

2. Considering the actual location of the vessel off-gas (VOG) ducting, will it ignite from the effects of the kerosene fire?

3. Will the VOG duct stop burning if the source fire is removed?

4. How well will the VOG duct (duct elbow) endure a simulated cubicle fire?

5. What effect will the heat and smoke produced by the burning solvent and/or burning duct have on the prefilter and HEPA filter array?

6. Will the fire become oxygen (O_2) limited and eventually go out?

7. Will the addition of water from fire sprinklers increase the challenge of the prefilters and HEPA's?

8. What is the temperature drop of the combustion gases from the test fire to the prefilters and HEPA's?

Both the FRD and ORNL determined that the only way to obtain conclusive results and to accurately analyze the fire performance of the ventilation system, fire protection system, prefilters/HEPA filter array, FRP VOG duct, etc. was to design and conduct a full scale fire test series. In order to design and construct a representative test article, we had to gain an accurate and detailed understanding of the actual facility layout, fire protection systems, facility operating procedures, and ventilation system and operation. FRD personnel toured Bldg. 7920 to obtain first hand insight into its configuration and operational parameters. However, since most of the significant areas were inaccessible, we spent a significant amount of time studying photos, building plans, facility SAR, and talking to knowledgeable people. Through numerous phone calls and facsimile transmissions to ORNL and Lockwood Greene, we were able to complete these tasks and began developing a detailed test design. The majority of our questions were answered and information provided by personnel from Lockwood Greene. Although general information was available from other sources, detail and historic questions were answered by Lockwood Greene. In fact, Lockwood Greene provided a great deal of help in developing the preliminary fire test matrix included as Table 4.

BUILDING 7920 FACILITY DESCRIPTION

As it turned out, NJ Alvares in his report [1] provided a good general facility description summary. It is, therefore, presented below:

Facility Specifications

"Figure N-1 is a plan view of the transuranium processing plant showing both office and operator's areas, and an isometric drawing of a typical cell in the operations area of the building. The shielded cell bank contains nine 7 ft. wide hot cells each with a 7 ft. long cubicle area, separated from each other by 2.0 ft. minimum thick concrete walls. Seven cells contain a tank pit area (9 x 22 ft. high). An inter-cell conveyor housing and the cell-ventilation exhaust duct run through the cubicle pits the full length of the cell bank.

"In the first seven cells air enters the south wall of the tank pit through a duct (10 in. diameter), the centerline of which is 21 ft. above the floor. The air exits the north wall of the tank pit to the cubicle pit through a slot (2 x 4 ft.) ten feet above the cell floor and is drawn into a cell ventilation duct (20 x 40 in.) through an opening (17.5 in. diameter) located 8.5 ft. above the cell floor.

"In the last two cells air enters the cubicle pit through a similar duct only 2' above the pit floor and exits to a cell ventilation duct. A waste-tank pit behind the last two cells and below the first-floor level is connected to each of the last two cubicle pits through a 2 ft square opening, but there is no air inlet to the waste pit and essentially no air flow between the waste tank pit and the last two cubicle pits.

"The air from all of the cells exits the cell ventilation duct through a 40 x 18 in. opening in the bottom of the duct in the Cell 5 cubicle pit and passes under the cell through a 37 ft. long, 30 in. diameter duct to the cell off-gas (COG) filter inlet plenum located within the building south of the cell bank.

"The volume of each tank pit is 1386 $ft.^3$ and the air supply to each is approximately 440 cfm."

Ventilation

"The off-gas systems ventilate components of the cell--the tanks, the cubicle, the cubicle pit, and the tank pit. Note that the tank and cubicle pits are served by COG ventilation with metal conduits. The vessel off-gas (VOG) header that collects effluent from the tanks is metal; the header that collects effluent from the cubicles is fiber-reinforced plastic (FRP). Because off-gases from the cubicles and tanks may contain hazardous materials, they are always passed through a caustic scrubber and possibly through carbon bed adsorbers.

"... The ventilation path comes in high and exits the tank pit through the access opening into the cubicle pit. In the cubicle pit a large metal duct collects this air and conveys it to an exhaust duct under the fifth cubicle where total flow is directed to the HEPA filter system before exiting through the stack. Inlet air is ducted high near the tank pit ceiling, and the air exit is at the half-height level into the cubicle pit. Total air flow through individual pit systems is approximately 440 cfm during normal operations."

PROJECT PLAN

A significant part of the project was to construct a test article which reproduced an actual Bldg. 7920 tank pit and cubicle pit in terms of size and configuration. An even more important part of the project was to reproduce the relevant parts of the containment ventilation system, not only in terms of ventilation components but also for normal and unique operating conditions. In addition, the fire protection system had to be simulated and installed. Furthermore, operational procedures had to be identified to define potential fire scenarios to be used to address the Tiger Team concerns. Our basic philosophy was to use the most severe credible scenario based on actual fact and be conservative for worst case situations, but not be ridiculously unrealistic. In general terms, the project plan identified the following areas to be studied:

1. The fire characteristics produced by a maximum credible solvent spill in both quantity and configuration.

2. The effect on the fire of varying the airflow rate, based on actual operational procedures.

3. The effect of turning off the cell airflow completely.

4. The response of the fire detectors and the effectiveness of the sprinkler system on extinguishing the fire.

5. The response of the filter system to the sprinkler water vapor and combustion products.

6. Ignitability and fire performance (thermal and smoke production) of the VOG duct in the Cell 3 tank pit.

7. Characterize the fire performance of the 30 mil epoxy coating on the pit concrete walls.

8. Characterize a cubicle fire and assess the ignitability and flame spread of the interior of a VOG ventilation duct elbow.

In order to define the fire risk to the REDC facility, the fire threat and the performance of the containment ventilation system had to be assessed. In reality, to determine the fire risk the probability of ignition would have to be taken into account. However, to evaluate the above characteristics, we assumed that the probability of ignition was 100%. Late in the test program we addressed the potential for kerosene ignition by electrical overload failures.

SOLVENT (KEROSENE) FIRE EXPERIMENTS

A significant phase of the study was to characterize the fire and smoke characteristics of a representative flammable solvent in realistic cell fire scenarios. From studying the flammability characteristics of the various solvents used in the TRU processes, it was decided that kerosene provided the most severe fire and smoke assault. It was also determined (through operational procedures, etc.) that the maximum possible spill in a tank pit would be 40 liters.

VOG DUCT FLAMMABILITY

Another Tiger Team concern was the potential for the ignition of the VOG duct in the tank pit and its subsequent contribution to the smoke loading of the filtration system. As mentioned previously, these ducts were of the same formulation as the actual Bondstrand ducts but did not have the asbestos inner liner. Our tests would place the duct in the most conservative position according to Cell 3 specifications. In this cell a horizontal section as shown in Figure

3 is only 3.5' from the floor. The duct would experience the most severe tank pit fire exposure in this orientation.

CUBICLE FIRE SIMULATION

The tests of the VOG duct addressed the fire response of the material from a fire source impinging on the duct's exterior and the resultant fire spread on the exterior of the duct. A fire in one of the cubicles would cause heat, flame, and smoke to be pulled into the FRP pipe and would challenge its interior. Depending on the severity of the cubicle fire, the interior flame spread could be much more severe than external fire spread. Because the exemplar ducts do not contain an asbestos interior lining, this test would be very conservative.

The simulated cubicle for this phase was built inside the tank pit mock up with the VOG elbow coming out of the ceiling with the specified airflow pulled through it. We characterized the probable cubicle fire.

EPOXY PANEL TEST

The Building 7920 pit surfaces (except the floor) are covered with a 30-mil layer of FRP laminate which is described in Table 3. We felt that because this coating was so thin and laminated to heavy concrete surfaces, the heat loss to the concrete would prevent the ignition of the FRP. However, we conducted a test with a thin cementitious substrate to evaluate the hypothesis.

TEST STRUCTURE

Both the FRD and ORNL determined that the only way to obtain conclusive results and to accurately analyze the fire performance of the ventilation system, fire protection system, prefilters/HEPA filter array, FRP VOG duct, etc. was to construct the full scale test article. In order to realistically assess the performance of the ventilation system under the postulated fire conditions, we wanted to simulate as near as possible a full-scale mock-up of a hot cell. The test article is shown graphically in Figures 1 through 5 and pictorially in Photos 1 through 4. The structure was a full-scale representation with the tank pit height at 22'. Note that the cubicle is not reproduced (it would be located where the enclosure steps down) because it plays no part in this phase of testing. The outline (shown in Figures 1-4) define where the cubicle would sit in the actual facility. The duct leading from the cubicle pit area had several bends and resulted in a total run of approximately 45' from the pit to the HEPA filter bank. This mock-up was modeled after cell #3 in terms of dimensions, ventilation layout, etc. The test article was constructed as a 2"x4" stud frame construction (Photo 3) with an inner liner of plywood for shear strength. The interior was lined with 2 layers of 5/8" Type "X" fire rated gypsum wallboard (Photos 8 & 9). The 2 layers were staggered to eliminate through seams and each seam was caulked with a silicone sealant to prevent air leakage. The sump floor construction was constructed to duplicate that in the actual facility. The access doors (Photo 7) shown in the structure are to facilitate test set-up, etc. Viewing ports are included in the doors so that the fire(s) can be viewed and photographed until it becomes obscured by smoke. A hatch in the roof of the tank pit was also provided for global viewing within the enclosure. The actual REDC cells are monolithically cast concrete with 2.0' thick walls and containment requirements dictate no leaks.

Figure 3 displays the dimensions of the tank pit and the cell area that would be below the cubicle. In the actual facility, due to the configuration of the cubicle within the cell, a quantity of air leaks past the cubicle into the lower pit area. We have simulated this leakage airflow with the two 12" diameter snap ducts with 90^{o} bends (total cross sectional area: 226 in^2) as shown in Photo 3.

Not only did we strive to duplicate the dimensional and volumetric dimensions of the structure but also any openings between the cells as well as the sloped floor and sump in the tank pit. To ensure that we reproduced the multi angled slopes of the floor, we first installed a number of metal "ribs," shown in Photos 5 & 6 duplicating the sump contours, then we poured concrete to duplicate the tank pit floor and installed a drain pipe (with plug). The 2' by 4' opening (Photo 10) located approximately 10' from the floor was provided between the tank pit and the cubicle pit. All penetrations were sealed and the two exterior access doors were specially designed to form a positive seal when secured. Since three separate types of fire tests were conducted in the test article, several modifications were made as the project progressed.

VENTILATION SYSTEM

The ventilation system to the tank pit and cell were reproduced as closely as possible to the actual REDC system as shown in Figures 1 & 2. As can be seen in Figure 4 air enters what would be the east wall of the LLNL tank pit mock up through a 10 in. diameter duct, the centerline of which is approximately 21 ft. above the floor. The air exits the west wall of the tank pit to the cubicle pit through a slot (2 x 4 ft.) ten feet above the cell floor and is drawn into a cell ventilation duct (20 x 40 in.) through an opening (17.5 in. diameter) located 8.5 ft. above the cell floor. This configuration which is shown in Figure 4 produces a unique air flow. What is not shown is the transient swirling pattern the air takes at the floor level. As will be seen in the test results, the oxygen available to the sump floor is greatly reduced by this airflow pattern. For these tests, three flowrates of 1000, 440, and 370 cfm were supplied to the tank pit representing a high, normal, and low airflow respectively. Once the air exits the test article it enters the main ventilation duct with a total exit air flow of approximately 3600 cfm. This ventilation rate is approximately half of the 7310 cfm that is the actual flow rate in the REDC facility. This cuts the dilution rate down considerably in terms of heat dissipation as well as smoke dilution.

The detailed specifications for the roughing and HEPA filters are included in Table 3. The filter enclosures were two AstroSEAL housings each designed for filters stacked one wide and three high. As shown in Figure 1, the pre or roughing filters were stacked in this three high and one wide configuration. Behind them were three 1000 cfm HEPA's also stacked three high and one wide. Both the inlet and exit duct to the filter housing were round 18" diameter metal ducting with a baffle at the inlet side. This baffle was designed to distribute the incoming air fairly uniformly to the three roughing filters. The ventilation air was pulled through the system by the LLNL variable speed blower. The primary specifications for this fan include:

- Buffalo Forge, Size 7E, F.S.
- Flowrate : 3000 cfm
- Speed : 3550 RPM, 26.4 BHP
- Efficiency : 52.5%
- Wheel Diameter : 22.75 in.

Twelve 10' (nominal 8" I.D.) sections of VOG duct and two 90^{o} (nominal 4" diameter) elbows are displayed in Photo 22. The 8" ducts were for the tank pit tests and the elbow was for the cubicle burns. These sections of duct were formulated to the original Bondstrand specifications shown in Table 3, but were not made by Bondstrand. Differences between these test samples and the actual REDC duct work is that our test ducts do not have the asbestos interior lining which would make the interior more fire resistive than the specimens fabricated for fire testing. It should be noted that these duct components were stored outside at LLNL, exposed to the elements for a number of months.

FIRE PROTECTION SYSTEM

The REDC cell and cubicle fire protection system consist of both fire detection and sprinklers. The system description as depicted in the SAR [2] is presented below:

> Each cubicle contains a thermopneumatic rate-of-rise device. Three rate-of-rise devices are located in each cell, one on top of the cubicles, one underneath the cubicle, and one near the top of the tank pit. The integrity of each system is monitored with a supervisory air signal which triggers an alarm in the event of failure. If any one of these devices in the cell bank detects a temperature rise of 8 to 11^{o} C/min. (15^{o} to 20^{o} F/min.), the main header

valve for the cell and cubicle preaction system is opened, a fire signal is activated at the annunciator panel in the operations control room, and a fire alarm is transmitted over the ORNL system. The cell and cubicle preaction system main header valve can be opened by an electric switch on the operations control panel. When a temperature of 80° C (175° F) is detected by one of three thermal switches located in each cell pit outside of the cubicles, a deluge valve is tripped and the cell is sprayed through nozzles located above the cubicle, underneath the cubicle, and in the tank pit. Individual deluge systems are provided for each cell so that a heat release in one cell does not cause any other cell to be deluged with water. Water is never released automatically into a cubicle. The deluge valve for a cubicle must be actuated by pressing and holding a push button on the cell face in the operating area. Each cubicle has a separate deluge system. We duplicated the salient parts of this system for assessment in these tests.

INSTRUMENTATION

In order to obtain pertinent data, a variety of areas and parameters had to be monitored and recorded. Those parameters of interest included but were not limited to:

- In tank pit and cubicle pit: severity of the kerosene fire in terms of temperature, pressure, light obscuration, heat release rate, combustion gas concentrations (oxygen, carbon dioxide, carbon monoxide, hydrocarbons), and heat fluxes.
- Ventilation system: inlet and outlet flow rates, in duct air temperatures, in duct light obscuration, node gas concentrations. Prefilter and HEPA filter delta P, temperatures, mass gain, etc.

Instrumentation was located as shown in Figures 1 and 5. All instruments were calibrated prior to each test or at their prescribed interval. It should also be noted that a remotely activated (manually) light water system was at standby at the cell tank pit for emergency extinguishment. The following summarizes what specific instruments were utilized and why. Primarily, most of the devices corroborated each other and identified any anomalous readings.

a. Thermocouples

- Temperature profiles were monitored and recorded 6" from the floor and every 2' vertically within the simulated cell tank pit at the two rake locations shown in Figure 5.
- Temperatures at the ceiling, near the heat detector, near the sprinkler head, and around any other significant device were monitored and recorded.

- Temperatures at other instrument locations such as gas and pressure probes were monitored.
- The four corners of the 2' x 4' opening between the tank pit and COG exhaust duct area were instrumented.

b. A pressure transducer was connected to the heat detector to monitor its response and to use it as the signal for sprinkler activation.

c. A calorimeter was installed to monitor thermal heat flux produced by the burning kerosene. It also provided us with an additional means of determining whether the fire was still burning.

d. O_2, CO_2, CO concentrations were monitored in three locations in the tank pit, high and low, and also within the ventilation duct work. From these data we were able to estimate the burning rate (or heat release rate) of the fire and whether it had become oxygen starved.

e. Total unburned hydrocarbons were measured in three locations, two within the cell tank pit and one in the ventilation duct work. This information was an indication of burning efficiency and also an indication of the formation and concentration of potential explosive mixtures.

f. Smoke density as determined by light obscuration measurements was taken at two locations in the ventilation duct work. Although not absolutely quantitative, these data provided an indication of the dynamic rate of smoke production from the the various tests. Although we had considered placing these devices in the tank pit, we felt that it would fill with smoke so rapidly that the data would not be useful.

g. Change in pressures were monitored within the cell tank pit as well as before and after the filter bank. Within the tank pit this data indicated the magnitude of the pressures and location of the neutral plane. The transducers at the filter bank provided a dynamic picture of filter loading.

h. Ventilation flow rates at the inlet duct and exhaust duct were measured as accurately as possible. In most locations we used a sharp edged orifice along with electronic turbine flowmeters.

i. The mass gain of the filters was measured for each test. Each prefilter and HEPA filter was weighed before and after each test to document mass loading. In addition, they were DOP leak tested in-place before and after each test.

j. Measuring the quantity of kerosene burned was not a straightforward task. After each test, any unburned kerosene was pumped out of the sump and volumetrically measured to estimate quantity burned. For those tests where sprinkler water was introduced, we were unable to determine the volume of kerosene that remained.

k. Hi band 8mm videotape and 35mm still photography were used to document within the tank pit for each test. A summary VHS videotape has been made for this project.

The primary instrumentation used in this study included:

1. Data Acquisition System: Hewlet Packard HP 3852 Data Scanner HP 9000 Model 340 Computer.

2. Oxygen, Carbon Dioxide, and Carbon Monoxide analyzers made by Infrared.

3. Total Hydrocarbon Analyzers made by Beckman and Baseline.

4. Radiometers made by HyCal and Medtherm.

5. Optical Detectors for light obscuration measurements.

6. Validyne Pressure Transducers.

7. Chromel-Alumel Thermocouples.

BASIC TEST PROCEDURE

We developed a formal test procedure which is summarized below:

a. Power up data acquisition system and verifiy.

b. Power up and calibrate (if required) all instrumentation.

c. Set, balance, and verify ventilation system airflows.

d. Weigh all filters and install.

e. DOP leak test all filters in-place.

f. Set-up photographic equipment.

g. Measure out appropriate quantity of kerosene and place into sump.

h. Start data acquisition system and cameras to take baseline data (approximately 2-5 minutes).

i. Remotely ignite kerosene with "extended tube" torch.

j. Instrument scan rate was 1 scan every 5 seconds.

k. Monitor differential pressure (delta p) on filters to ensure plugging does not occur.

- If plugging did not occur and fire did not become oxygen starved, then it was allowed to burn to completion.
- If filters plugged, then the ventilation system would be switched over to the air pollution control (APC) system and the test terminated.
- If sprinkler activation or the light water system was activated, then we would look at data to determine when it extinguished. It was impossible to determine this fact visually.
- We used the same procedure to determine if the fire were extinguished by oxygen depletion.

l. Once the test was terminated, the cells were ventilated through the APC unit or until safe conditions as described in the Operational Safety Procedure were reached. Only at this time were personnel allowed to enter. The data acquisition system was then shut down.

m. All filters were DOP checked and then weighed after each test.

n. Any unburned kerosene was pumped out and, if possible, the quantity was estimated. In the case of those tests that required ventilation shut-off, we closed the air inlet vent to the tank pit at the appropriate time to stop ventilation into the cells. For those tests where the sprinkler was activated, we predetermined when to fire the sprinkler based on actual operating parameters.

o. Note that all tank pit tests, including the panel test utilized 40 liters (10.6 gal.) of kerosene.

TEST SERIES

The initial and primary set of fire experiments was an extensive evaluation of solvent or kerosene fires. The characteristics of these tests are summarized in Table 1, and are described below. Although the preliminary test plan was a matrix (see Table 4) of twelve solvent fueled tests, as we got into the program we determined that we could do away with or modify a number of the tests.

Each of the baseline solvent tests (ORNL 1-3) was designed to burn 40 liters of kerosene as a catastrophic spill and permitted to burn without sprinkler intervention. Each run was conducted at different ventilation rates into the tank pit (entering the upper region). These rates were 370, 440, ands 1000 CFM, which correspond to the actual rates for REDC cells (minimum, normal, and maximum respectively). The tests were allowed to burn until the fire went out by consuming all the fuel, by oxygen starvation, or some other reason. These tests were designed to determine the course of a solvent fire at the three ventilation rates and simulating a sprinkler system failure. They would demonstrate whether a solvent fueled fire would sustain burning at the floor level of the tank pit. This series was the initial use of the new prefilters and HEPA filters. These runs were designed to acquire data to better quantify the effects of smoke particulate produced solely by the burning solvent.

ORNL 1.0

The initial test in the series is shown as number 1 on Table 1. The air flow rate of 1000 cfm reproduced the maximum that would exist in the REDC cells and would supply the greatest amount of oxygen to a developing fire which would make it the worst case scenario. Photo 17 is a pre test photo which shows the cell floor and the kerosene pool. The simulated spill was rectangular in shape with dimensions that were approximately 5'-2" by 4'-0" with a maximum depth at the sump corner of 1-1/8". Also shown in Photo 18 are the remote kerosene fill spout and remote ignition port (where the light is poking through).These dimensions were very close to those predicted on the basis of tank pit floor slope and various quantities of spilled solvent. The Hi band 8mm video camera mounted on the roof of the tank pit provided an excellent plan view of the fire until conditions became too smokey, which was nearly immediate. As mentioned in the test procedure, the prefilters and HEPA filters were weighed and in-place leak tested before and after each test.

Ignition of this quantity of kerosene was difficult. As mentioned previously, we remotely ignited the fuel through a pipe on the west wall using large paper wipes as wicks and a propane torch with an extended neck. Even with the severity of the ignition source, this process would still take several minutes to achieve self sustained ignition. Once ignition was verified the propane torch was removed and the pipe sealed from the outside. Data plot,

Figure 1.6 which is a multi plot shows that the initial tank pit airflow was approximately 1060 cfm and the dilution air flow was approximately 2600 cfm for a total of 3660 cfm. Although the tank pit airflow is close to the actual, the dilution flow is much less than the actual. The total airflow rate was about half the dilution that would exist in the actual REDC ventilation system which makes these tests much more conservative than the actual situation. That is, the smoke particulate concentration would be twice as high in our fire tests. Following a temperature progression from the area of the fire to HEPA filters:

1. Figure 1.3 shows the South (So) TC rake with a maximum fire temperature over 900°C.

2. Figures 1.1 and 1.2 of the Northeast (NE) rake shows a maximum temperature profile from 400°C 6" from the floor to 250°C 6" from the ceiling.

3. The maximum air temperatures through the opening between the two cell pits ranged from 250°C to 500°C (Figure 1.4).

4. The maximum cell manifold air temperature as shown in Figure 1.10 was approximately 240°C and the cell exhaust air temperature was a little over 120°C (Figure 1.10).

5. Maximum air temperature before the prefilter was approximately 50°C (Figure 1.10) and before the HEPA filters was approximately 40°C. We can see that there is a tremendous temperature drop from the fire area (860°C) to the filter housing.

6. The response of the heat detectors displayed in Figure 1.9 are almost instantaneous with fire start.

In ORNL 1.0 the fire went out from oxygen starvation in approximately 60-80 seconds. Studying the data plots, we can determine that the fire was ignited at 240 seconds and went out at 300-320 seconds. The time at which the fire extinguished was substantiated by the following corroborating data:

1. Temperatures peak and drop off drastically at 320 sec.

2. Cell oxygen near the fire (Figure 1.8) drops to a minimum of about 13% at 320 sec.

3. Cell carbon dioxide (Figure 1.8) and carbon monoxide peak at 6% and 0.28% respectively at 320 sec.

4. Unburned hydrocarbons (Figure 1.8) jumps from 700 to 7000 ppm beginning at 320 sec. indicating that the fire is out but the residual heat was causing the unburned kerosene to vaporize.

5. Light transmittance near cell (Figure 1.5) drops to a low of 10% then starts back up at approximately 300 sec. Before the filters the transmittance drops to 0% at 300-320 sec. and then starts back up. The percentage figures mean that smoke particulate has become so dense that 10% and 0% (none) of the light passed through.

Our volumetric post test measurement of kerosene was 16.6 liters which indicates that 23.4 liters were consumed in the fire. This figure is obviously incorrect, considering the fire only burned for a little over a minute. Because this was the first full scale test in the series, there were a number of things in our procedure that threw this figure off:

- A finite quantity of kerosene soaked into the concrete floor.
- Since we left the the blower on for at least 24 hours after the test before kerosene removal, much of it evaporated into the air.
- We were not as careful in the removal process as we should have been.

It is more reasonable to use the loss figure produced by later tests that burned for approximately the same period of time.

Table 2 summarizes the performance of the pre filters and HEPA filters. Note that the total mass loading on the former was 179g and on the latter was 68g. Remember that a quantity of this soot plated out on the walls of the enclosure as well as in the duct work. The DOP testing, before and after the test, of the filter array by our lab Industrial Hygienists was 0.01 % penetration. DOP testing for this test and all others was conducted with the prefilters and HEPA's in-place and undisturbed. All certification sheets are included in this report as Appendix A.

ORNL 2.0

The second test in the series had a cell air flow rate of 440 cfm which represented normal cell operation. The basic test procedure was followed and was identical to the first test.

Figure 2.6 which is a multi plot shows that the initial tank pit airflow was approximately 440 cfm and the dilution air flow was approximately 3200 cfm for a total of 3640 cfm. Following a temperature progression from the area of the fire to HEPA filters:

1. Figure 2.3 shows the So TC rake with a maximum fire temperature of approximately 840°C.

2. Figures 2.1 and 2.2 of the Northeast (NE) rake shows a maximum temperature profile from 340°C 6" from the floor to 225°C 6" from the ceiling.

3. The maximum air temperatures through the opening between the tank and cubicle pits ranged from 175°C to 300°C (Figure 2.4).

4. The maximum cell manifold air temperature as shown in Figure 2.10 was approximately 130°C and the cell exhaust air temperature was about 60°C.

5. Maximum air temperature before the pre filter was approximately 27°C (Figure 2.10) and before the HEPA filters was approximately the same. We can see, like the first test, that there is a tremendous temperature drop from the fire area to the filter housing.

6. Response of heat detectors: (Figure 2.9) were almost instantaneous with fire initiation.

The fire went out from oxygen starvation in this second experiment just as it did in the initial test. Because the airflow is less than half of that in ORNL 1.0 we would expect this result. It appears that the flame extinguished in approximately 120 seconds. The data show that the fire burned from about 140 sec. and went out at 260 sec. into the test. Again, the substantiating data was the following:

1. Temperatures begin to rise at 140 sec., peak and drop off drastically at 260 sec.

2. Cell oxygen near the fire (Figure 2.8) drops to a minimum of about 13% at 260 sec.

3. Cell carbon dioxide (Figure 2.8) and carbon monoxide (chan. 82) peak at 5.7% and 0.29% respectively at 260 sec.

4. Unburned hydrocarbons (Figure 2.8) begins to increase from about 260 sec. to a peak of 12 500 ppm at 300 sec.

5. Light transmittance near cell (Figure 2.5) begins falling to a low of 8% at about 140 sec. then starts back up at approximately 260 sec. Before the filters (Figure 2.5) the transmittance drops to 45% at 260 sec. and then starts back up.

Our rough measurement of unburned kerosene showed that about 31.65 liters remained which meant that only 8.35 liters burned or evaporated. Table 2 summarizes the performance of the prefilters and HEPA filters. Note that the total mass loading on the former was 97g and on the latter was -50g. This minus figure for the HEPA filters indicates that whatever loading was on these filters was volatile and evaporated off. Remember that a quantity of this soot plated out on the walls of the enclosure as well as in the duct work. The DOP testing, before and after the test, of the filter array by our lab Industrial Hygienists was 0.01 % penetration.

ORNL 3.0

The third test in the series used the minimum cell air flow of 370 cfm. The basic test procedure was followed and the results can be summarized as follows:

The multi plot shown in Figure 3.6 shows the initial tank pit airflow rate was approximately 370 cfm and the dilution air flow was approximately 3230 cfm for a total of 3600 cfm. As we did in the previous tests, we look at the temperature progression from the area of the fire to HEPA filters:

1. Figure 3.3 shows the So TC rake with a maximum fire temperature of approximately 900°C.

2. Figures 3.1 and 3.2 of the Northeast (NE) rake shows a maximum temperature profile from 340°C 6" from the floor to 215°C 6" from the ceiling.

3. The maximum air temperatures through the opening between the tank and cubicle pits ranged from 170°C to 299°C (Figure 3.4).

4. The cell manifold maximum air temperature as shown in Figure 3.10 was approximately 105°C and the cell exhaust air temperature was about 50°C (Figure 3.10).

5. Maximum air temperature before the pre filter and before the HEPA filters were both approximately 29°C (Figure 3.10). As with the previous tests, there was a tremendous temperature drop from the source fire to the filter housing.

6. Response of heat detectors: (Figure 3.9) were almost instantaneous with fire ignition.

This third fire also extinguished from oxygen starvation in approximately 60 seconds. Due to the minimal airflow, this fire should have been of the shortest duration. The data show that the fire ignited at about 120 sec. and went out at 180 sec. into the test. Again, the substantiating data was the following:

1. Thermocouple rake temperatures begin to rise at 120 sec., peak and drop off drastically at 180 sec.

2. Cell oxygen near the fire (Figure 3.8) drops to a minimum of about 13% at 210 sec.

3. Cell carbon dioxide (Figure 3.8) and carbon monoxide peak at 5.7% and 0.30% respectively at 210 sec.

4. Unburned hydrocarbons (Figure 3.8) begins to increase from about 170 sec. to a peak of 17 500 ppm at 300 sec.

5. Light transmittance near cell (Figure 3.5) begins falling to a low of 8% at about 190 sec. then starts back up at approximately 240 sec. Before the filters (Figure 3.5) the transmittance drops to 57% at 260 sec. and then starts back up.

We measured about 31.2 liters of unburned kerosene which meant that only 8.8 liters burned or evaporated. Table 2 summarizes the performance of the prefilters and HEPA filters. Note that the total mass loading on the former was 86g and on the latter was 2g. Remember that a quantity of this soot plated out on the walls of the enclosure as well as in the duct work. The DOP testing, before and after the test, of the filter array by our lab Industrial Hygienists was 0.01 % penetration..

ORNL 4.0

Test ORNL 4.0 was conducted at 1000 cfm flow rate in the tank pit with the VOG duct work installed according to the specifications for Cell 3. As shown in Figure 3, the lowest horizontal section was over the access way at a height of approximately 3.5' from the floor. Air was pulled through the FRP duct work with the blower and flex hose shown in Photo 25. Like the earlier ones, this test was run without sprinkler intervention and was permitted to burn until it extinguished from oxygen deficiency.

The multi plot shown in Figure 4.7 shows the initial tank pit airflow rate was approximately 1000 cfm and the dilution air flow was approximately 2600 cfm for a total of 3600 cfm. Studying the temperature progression from the area of the fire to HEPA filters indicates:

1. The multi plot included as Figure 4.3 shows that the temperature profile for this experiment was fairly uniform at the So TC rake with a maximum fire temperature of approximately 925^{o}C very early in the burn. After this early peak, the temperatures oscillate greatly as the fire seeked out oxygen within the cell.

2. Similar behavior was noted at the NE rake but with the fire finally peaking at about 500°C. Figures 4.1 and 4.2 show that for the most part the temperatures sat between 200°C and 300°C.

3. The maximum air temperatures through the opening between the two cells after an early peak of 450°C ranged from 150°C to 340°C (Figure 4.4).

4. The maximum cell manifold air temperature as shown in Figure 4.10 was approximately 200°C and the cell exhaust air temperature was about 140°C .

5. Maximum air temperature before the prefilter and before the HEPA filters were both approximately 60°C (Figure 4.10). As with the previous tests, there was a tremendous temperature drop from the source fire to the filter housing.

6. Response of heat detectors: (Figure 4.9) were almost instantaneous with the ignition of the fire. The H.A.D. in the tank pit had a transducer malfunction.

This fire went out from oxygen starvation after burning for over 10 minutes. This extended duration burning was most likely due to the altered airflow pattern caused by the installation of the FRP VOG duct work. Its configuration was somehow causing more air to run down the wall and entrain into the fire. The data illustrates that the fire ignited at approximately 150sec. and extinguished at about 750 sec. Test 4.0 burned for quite a bit longer than ORNL 1.0-3.0. Actually, the longer fire duration was a severe test for evaluating the VOG duct work. Again, the substantiating data was the following:

1. Thermocouple rake temperatures begin to rise at 150 sec., peak and drop off drastically at 750 sec.

2. Cell oxygen near the fire (Figure 4.5) drops to a minimum of about 13% at 750 sec. and then quickly returns to ambient.

3. Cell carbon dioxide (Figure 4.5) and carbon monoxide (Figure 4.5) peak at 5.7% and 0.28% respectively at 750 sec.

4. Unburned hydrocarbons (Figure 4.5) increases from about 725 sec. to a peak of 15 000 ppm at 800 sec.

5. Due to the cyclic nature of this fire the light transmittance data reaches a minimum at about 200 seconds then oscillates as can be seen in Figure 4.6.

Our rough measurement of unburned kerosene was about 27.6 liters which meant that 12.4 liters burned or evaporated. Table 2 summarizes the performance of the prefilters and HEPA filters. Note that the total mass loading on the former was 123g and on the latter was 29g. The DOP testing, before and after the test, of the filter array by our lab Industrial Hygienists was 0.01 % penetration.

Post test examination showed that the FRP duct work did not suffer any thermal damage anywhere. Photos 26, 27, and 28 display a uniform soot layer on the entire duct run. When this layer was wiped off where the duct was closest to the fire (Photos 29 & 30), the material was totally undamaged beneath. The FRP duct work was left in place for the remainder of the test series to assess its fire resistance. Furthermore, the prefilters and HEPA filters have successfully endured four full scale kerosene fires at this point. However, as Photos 19, 20, & 21 illustrate the prefilters were replaced after this test.

ORNL 5.0

Test ORNL 5.0 was also conducted with a 1000 cfm being supplied to the tank pit. This experiment was conducted to determine whether shutting of the inlet airflow would extinguish the fire in a timely manner. Therefore, as soon as the heat detector displayed the appropriate rate of rise, the 1000 cfm inlet air to the tank pit was shut off.

The multi plot shown in Figure 5.7 shows the initial tank pit airflow rate was approximately 1000 cfm and the dilution air flow was approximately 2600 cfm for a total of 3600 cfm. The data illustrates that the fire was ignited at approximately 230sec. After the HAD fired (Figure 5.9), the airflow was shut off and as shown in Figure 5.7, it was down to 0 cfm at 280 sec. All data shows that the fire was extinguished within 35-40 seconds.

1. The multi plot (Figure 5.3) of the So TC rake indicates that immediately after 280 sec. the temperatures drop off.

2. The NE rake (Figures 5.1, 5.2), the temperatures around the window (Figure 5.4), and all other temperatures all peak and drop off very close to 280 sec.

3. Cell oxygen near the fire (Figure 5.5) begins to drop at around 280 sec. and hits a minimum of about 12% at 315 sec.

4. Cell carbon dioxide (Figure 5.5) and carbon monoxide peak at 6.6% and 0.32% respectively at 315 sec.

5. Unburned hydrocarbons (Figure 5.5) ramps up from about 280 sec. to a peak of 12 500 ppm at 350 sec. and continues to about 550 sec.

6. Light transmittance near cell (Figure 5.6) drops to a low of 10% at 280 sec. then starts back up. Before the filters the transmittance drops to 42% also at 280 sec. and then begins to increase.

Our rough measurement of unburned kerosene was about 34 liters which meant that only 6.0 liters burned or evaporated. Table 2 summarizes the performance of the prefilters and HEPA filters. The total mass loading on the former was 85g and on the latter was -126g. The leakages for the filter train which were certified by our lab Industrial Hygienists was 0.01 % penetration. Also, the FRP VOG duct work did not ignite nor suffer any damage.

ORNL 6.0

The sixth test was a repeat of ORNL 5 except that the cell airflow was reduced to the normal rate of 440 cfm. Although this experiment was a confirmation of extinguishing the fire by shutting down the oxygen, it was also to see if the initially reduced airflow made any difference.

The multi plot included as Figure 6.7 shows the initial tank pit airflow was approximately 430 cfm and the dilution air flow was approximately 3160 cfm for a total of 3600 cfm. The fire was ignited somewhere around 80 sec. After the HAD fired (Figure 6.9), the airflow was shut off and as shown in Figure 6.7, it was down to 0 cfm at 140 sec. and the fire was extinguished by oxygen starvation at about 180 sec. (about the same amount of time as ORNL 5.0), 35-40 sec.

1. The multi plot (Figure 6.3) of the So TC rake indicates that immediately after 120 sec. the temperatures drop off.

2. The NE rake (Fig. 6.2), the temperatures around the window (Fig. 6.4), and all other temperatures (Fig. 6.1) all peak and drop off very close to 140 sec.

3. Cell oxygen near the fire (Figure 6.5) begins to drop at around 100 sec. and hits a minimum of about 12.4% at approximately 150 sec.

3. Cell carbon dioxide (Figure 6.5) and carbon monoxide peak at 6.3% and 0.27% respectively at 140 sec.

4. Unburned hydrocarbons (Figure 6.5) begin to increase from about 120 sec. to a peak of 16 000 ppm at 370 sec.

5. Light transmittance near the cell (Figure 6.6) drops to a low of 5% at 120 sec. then starts back up. Before the filters the transmittance drops to 52% also at 120 sec. and then starts back up. Our rough measurement of unburned kerosene was about 34.5 liters which indicates that only 5.5 liters burned or evaporated.

Table 2 summarizes the performance of the prefilters and HEPA filters. The total mass loading on the former was 115g and on the latter was -29g. The DOP testing, before and after the test, of the filter array by our lab Industrial Hygienists was 0.01 % penetration. Also, the FRP VOG duct work did not ignite nor suffer any damage.

ORNL 7.0

The seventh experiment was the first to assess the effect of the deluge sprinkler head shown in Photo 31. Although the sprinkler head that exists in the actual tank pit is no longer available, we were able to obtain a head with the same specifications in terms of spray pattern and output. The specifications for this sprinkler head are presented in Table 3. The spray pattern can be seen in Photo 32 and Photo 33 displays the head installed in the correct location in the tank pit. The purpose of the sprinkler tests was to evaluate its effectiveness on the fire and also whether the addition of water vapor to smoke would plug the prefilters and/or HEPA filters.

The procedure for this experiment was to simulate the actual operation of the fire detection and fire sprinkler system. In typical operation, the deluge sprinkler would be activated after the HAD rate of rise exceeded 8^{o}C to 10^{o}C per second and the temperature reached 175^{o}F (~80^{o}C). We monitored the temperature at the 20' height (location of sprinkler head) in the tank pit as well as the rate of rise of the HAD and manually activated the sprinkler 15 seconds after the thermocouple at 20' reached ~80^{o}C and let it run for 2 minutes. To challenge the filters even more, we let the ventilation system continue to function for an hour after test termination.

The multi plot shown in Figure 7.7 shows the initial tank pit airflow rate was approximately 1000 cfm and the dilution air flow was approximately 2600 cfm for a total of 3600 cfm. From Figure 7.2 (thermocouple at 20') we can see that the temperature hit 80^{o}C at approximately 365 seconds which means that the sprinkler was activated at about 380 seconds.The So rake multi plot (Figure 7.3) shows that the sprinkler was almost instantaneously effective as the fire peaks and immediately cools down at around 380 seconds. All other temperature data also drop off drastically immediately after sprinkler activation. The oxygen concentration in Figure 7.5 shows a dip to a low of 15% at 420 seconds but the slope starts down at 380 seconds, demonstrating the air displacement around the fire caused by the sprinkler spray.Similarly, the carbon dioxide (Figure 7.5) and carbon monoxide (Figure 7.5) production both begin to increase at about 380 seconds and peak at 420 seconds at 4.5 % and 0.2% respectively. From Figure 7.5 we can see that the total hydrocarbons began to increase at 380 seconds and peaked at approximately 14 500 ppm at 440 seconds. And, lastly, light transmittance both near the cell (Figure 7.6) and before the filters (Figure 7.6) drops to a low of 4% at 390 sec. then starts back up.

Due to the quantity of accumulated sprinkler water, we were unable make even a rough estimate of the quantity of kerosene remaining. Table 2 summarizes the performance of the prefilters and HEPA filters. Note that the total mass loading on the former was 82g and on the latter was 47g. The DOP testing, before and after the test, of the filter array by our lab Industrial Hygienists was 0.01 % penetration. As mentioned earlier, the cells remained sealed after the test with the ventilation air running at 1000 cfm into the cell (Figure 7.13) and 3600 cfm total for an additional hour. There was no effect on the prefilters nor the HEPA filters as shown by the delta p in Figure 7.14. Also, the VOG duct work did not ignite or suffer any damage.

ORNL 8.0

The eighth experiment in the series was also an assessment of the effects of the sprinkler spray on the fire and the filters. However, for ORNL 8.0 the airflow was reduced to the normal cell flow rate of 440 cfm and dilution air of 3160 cfm for a total of 3600 cfm. The procedure for this experiment was identical to the previous test except that we allowed the sprinkler to flow for 5 minutes (3 minutes more than ORNL 7.0). And again, we left the enclosure sealed and let the ventilation system continue to run for an hour after test termination.

The multi plot shown in Figure 8.7 shows the initial tank pit airflow rate was approximately 440 cfm and the dilution air flow was approximately 3160 cfm for a total of 3600 cfm. All data shows that the fire was extinguished within 35-40 seconds. From Figure 8.3 (thermocouple at 20') we can see that the temperature hit 80°C at approximately 130 seconds which means that the sprinkler was activated at about 145 seconds.Like the previous sprinkler test, the So rake multi plot (Figure 8.2) shows that the sprinkler was almost instantaneously effective as the fire peaks and immediately cools down at around 145 seconds. All other temperature data also drop off drastically immediately after sprinkler activation. The oxygen concentration in Figure 8.5 shows that the fire really never got the chance to consume oxygen and produce significant quantities of carbon dioxide and carbon monoxide. However, from Figure 8.5 we can see that the total hydrocarbons began to increase at 160 seconds and peaked at approximately 16 000 ppm at 300 seconds. The light transmission instrumentation (Figure 8.6) appeared to be slow to react and may have been effected by the sprinkler water vapor.

We were again unable make an estimate of the quantity of kerosene remaining because of the large quantity of sprinkler water. Table 2 summarizes the performance of the prefilters and HEPA filters. Note that the total mass loading on the former was 184g and on the latter was -16g. The DOP testing, before and after the test, of the filter array by our lab Industrial Hygienists was 0.01 % penetration. As mentioned earlier, the cells remained sealed after the test and the ventilation running at 440 cfm into the cell and 3600 total air (Figure 8.13) for an additional hour. Like ORNL 7.0, there was no effect on the pre filters nor the HEPA filters as shown by the delta p in Figure 8.14. It should be noted that the same HEPA filters have been used through all eight tests and the prefilters were changed out after ORNL 4.0. Also, the VOG duct work was exposed to all test fires beginning with ORNL 4.0 and has not suffered any damage.

ORNL 9.0

The final test in the tank pit addressed the question of the flammability and smoke generation characteristics of the epoxy coating on the tank pit walls. This coating was System No. 1 Amercoat 66-3 with Thalco 1522 woven glass fiber. Its specifications are included in Table 3. As mentioned above, the concern was that because this material is a plastic, it would burn and produce a great deal of smoke that would contribute heavily to the loading of the roughing and HEPA filters. Our test of this material was very conservative because the actual REDC cells are constructed of concrete walls that are a minimum of 2.0' thick. The actual epoxy coating is only 30 mils thick and is a fairly flame resistant polyamide cured epoxy polymer. In a real fire situation, the concrete wall would act as a heat sink which would minimize if not prevent the burning of the coating. Recall that our simulated tank pit walls were lined with two layers of 5/8" Type X gypsum wallboard. The density of normal concrete is approximately 150 $lbs./ft.^3$ and that of gypsum wallboard is only 80-90 $lbs./ft.^3$. Consequently, coating the inside of the test enclosure would not be a realistic evaluation. Therefore, ORNL and Lockwood Greene had a construction material called "Wonder Board" coated with the epoxy coating. Personnel from Lockwood Greene were told that the Wonder Board was non combustible or of low combustibility because it was made from a cementitious material.

In order to assess the epoxy coating material ORNL contracted to have an Amercoat distributor apply the epoxy coating on 30" x 36" x 1/2" thick panels of Wonder Board. Twelve of these panels were produced in Tennessee and shipped to LLNL. We then attached the panels with screws inside the tank pit mock-up as shown in Figure 5 and in Photo 34. This experiment was set-up and conducted with 40 liters of kerosene in the same manner as the previous tests. The multi plot shown in Figure 9.7 shows the initial tank pit airflow rate was approximately 1000 cfm and the dilution air flow was approximately 2200 cfm for a total of 3200 cfm. From the multi plot of the So thermocouple rake (Figure 9.3) it can be seen that the kerosene was ignited at approximately 180 seconds and the fire extinguished from oxygen starvation at about 1580 seconds.

As it turned out, the Wonder Board itself ignited and contributed to the fire. Most of the burning took place on the back of the panels. An airflow pattern developed that ran down the wall and behind the very narrow space between the panels and the gypsum wallboard. Although we were not able to obtain an accurate weight measurement, our physical inspection of the panels after the test indicated that none of the polyamide cured epoxy burned and contributed to the fire. However, it appeared that some of the binder had been driven off by the heat in the areas where the epoxy coating was exposed directly to flame. As shown in Photo 38 the 30 mil coating is still intact, it just felt a little more brittle than in its virgin state. Also, post test inspection showed that approximately 50% of the panel area was affected by this heating. More significantly, it appears that combustible additives and the fiberglass mat in the Wonder Board ignited and continued to burn. From visual observations during the test, these additives appeared to be the fuel for flames shooting out from behind the panels for the duration of the fire. As mentioned earlier in the actual REDC tank pits and cells the epoxy coating was applied directly to the heavy, noncombustible concrete walls. However, the duration of this fire provided a worst case attack on the prefilters and HEPA filters. Both sets of filters performed well. Table 2 summarizes the performance of the prefilters and HEPA filters. The total mass loading on the former was 261g and on the latter was 240g. The DOP testing, before and after the test, of the filter array by our lab Industrial Hygienists was 0.01 % penetration.

The So rake multi plot (Figure 9.3) displays an early maximum temperature of 840°C and the fire oscillating from about 240°C to 675°C for the duration of the test. The NE rake graphs shown in Figures 9.1 and 9.2 display a fairly uniform temperature up through the tank pit profile averaging about 300°C. The light obscuration plots (Figure 9.6) seem to show a steady obscuration as the test continues. Figure 9.5 illustrates that the oxygen concentration was bordering on 13% throughout most of the burn, until it finally extinguished at 1600 seconds. The carbon dioxide and carbon monoxide production (Figure 9.5) follow the same pattern with concentrations dropping off at 1600 seconds. Finally, total unburned hydrocarbons shown in Figure 9.5 jump up to 17500 ppm at 1600 seconds.

Photos 35, 37, and 38 display the post condition of the Amercoat and also the backside of the Wonder Board (Photo 36). Although some of the binder seemed to "cook" out of the panels directly adjacent to the flame, there was little damage to the coating. There appeared to be more burning of the Wonder Board. As mentioned earlier the density of these panels were only a fraction of the concrete walls within the actual tank pit and cells. This test was, therefore, very conservative.

ORNL 10.0

The previous tests of the VOG duct (ORNL 4.0 through 9.0) primarily addressed the fire response of the material from an external fire source and potential ignition and fire spread on the exterior of the duct. A fire in one of the cubicles would cause heat, flame, smoke to be pulled into the FRP pipe and would challenge its interior. Depending on the severity of the cubicle fire, the interior flame spread could be much more severe than external fire spread. The 90 degree elbow that exits the cubicle would probably be subjected to the most severe fire effects. It was even more severe in the LLNL tests because the fabricated test specimen did not have the asbestos inner liner which is in the actual VOG elbow.That was the objective of this final test.The cubicle mock-up for this phase was built within the tank pit as shown in Figure 6 and Photo 40. Also Photo 39 displays the pans used to hold the 8 liter kerosene spill postulated for a cubicle accident. Although other potential fuels in the cubicles such as polyethylene tubing, rags, etc. might exist in minute quantities, the major fire threat would be the ignition of a catastrophic solvent spill. Polyethylene burns cleanly, as does the other trace materials. As demonstrated by the previous experiments, burning kerosene produces copious quantities of smoke. The VOG elbow leading out from the ceiling can be seen in Photo 40 and a close-up of it in Photo 41. Note that there is a fair amount of distance between the kerosene sump and the VOG opening in the ceiling. Air was pulled through the elbow at 10-16 cfm which is the estimated ventilation flow in the actual cubicles.

A thermocouple rake labeled So was installed with the first sensor 6" from the floor with three more in 2' increments. Also, gas sampling tubes were located at the 6' height in the cubicle. Figure 10.2 shows that the kerosene was ignited at about 110 seconds, peaked at approximately 600^{O}C and began to go out at 195 seconds. The oxygen concentration (Figure 10.4) bottomed at 13% at around 240 seconds which is when the fire extinguished from lack of oxygen. The carbon dioxide and carbon monoxide both peak at about 235 seconds which corresponds to the drop in oxygen concentration. Unburned hydrocarbons (Figure 10.4) show a rapid increase at 225 seconds and peaking at over 15 000 ppm around 450 seconds. Because this experiment was an assessment of the FRP elbow, a thermocouple was placed at the ceiling inlet and on the outside surface of the duct. From the multi plot (Figure 10.1) it can be seen that the inlet temperature peaks at 270^{O}C at 195 seconds. The exterior surface thermocouple (Figure 10.1) illustrates that the temperature barely rose above ambient which shows that the elbow did not suffer any thermal damage. The post test condition of the elbow is illustrated in Photo 43.

ORNL 11.0

ORNL 11.0 was a repeat of the previous experiment and it yielded nearly identical results.

ORNL 12.0 and 12.1

We felt that the previous two tests, although realistic, did not severely challenge the FRP elbow. We, therefore, conducted ORNL 12.0 and ORNL 12.1 with the same elbow, instrumentation, but a natural gas burner rather than a kerosene pool. ORNL 12.0: As shown in Photo 42 the burner flame was located directly beneath the ceiling opening of the elbow so that the flame was pulled into it by the ventilation flow. Figure 12.1 illustrates that the duct interior was exposed to temperatures of 600°C to 720°C for nearly 60 seconds with no ignition. The exterior surface temperature rose to a maximum of of about 40°C.

ORNL 12.1 was a repeat of this test, however, the burner was held to the opening for 400 seconds (6.7 min.) as displayed in Figure 12.2. Also, the flame was made larger in this test so that the flame would not be extinguished by the ventilation system, it was being sucked off the burner. It also shows that temperature oscillated between 360°C and 720°C for the duration of the fire. As before the duct did not ignite and the exterior surface temperature reached a maximum temperature of about 100°C.

SPARK OR ARC IGNITION TESTS

In order to evaluate the fire performance of the REDC air filtration system, we had to assume positive ignition of the kerosene by some means. In the actual tank pits and cells of the REDC there are very few potential ignition sources. However, one possibility that was brought up by the Tiger Team was the kerosene ignition by spark energy. It should be remembered the great difficulty we had in igniting the flammable liquid pool even with a propane torch and wads of paper.

To address the potential arcing ignition issue we conducted several different scenarios of 12 gage wire powered by the welding machine shown in Photo 44. Photos 45 thru 47 chronicle the overheating of a wire submerged in a pool of kerosene. The welding machine provided 200 amps of current, which is far greater than anything that exists in the actual facility. Although the insulation on the wire ignited and burned, the kerosene never sustained burning. Other tests were conducted with wire electrodes producing an arc across the gap which produced negative results in terms of ignition and sustained burning. All these tests were recorded on the videotape of this entire test program. It is not surprising that we were not able to achieve ignition with these electrical failures. A sufficient quantity of flammable liquid must be vaporized before ignition and sustained burning occurs.

THERMAL ANALYSIS OF FRP VOG DUCT MATERIAL

In order to obtain some basic information for the FRP duct, we conducted Thermogravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC). TGA produces a weight loss history of a representative sample which weighs about 10 mg as it is heated at a specified temperature ramp in a controlled atmosphere over a specified period of time. This analysis produces specific characteristics of thermal decomposition of a material such as onset of thermal degradation, the rate of degradation, and the residual weight remaining after degradation is complete. The onset of thermal degradation is a rough indication of the ignition temperature of the material. The residual weight remaining is an indication of the non combustible components of the test material. DSC also exposes a sample to a controlled temperature rate in a controlled atmosphere for a specified period of time. DSC analysis gives the endothermic and exothermic history associated with the transitions taking place as the sample heats up. These data provide information such as a material's melting temperature or when it begins to decompose.

A TGA was performed on exemplar pieces of 8" duct and 4" elbow specimens. The thermograms are presented as Figures 7 and 8 respectively. The heating rate for both specimens was 20^{o} C per minute. The 8" duct started as a 20.57mg sample and the elbow at 11.966 mg. As can be seen, both test specimens exhibit very similar thermograms which indicate that they are probably of the same formulation. From Figure 7 (not the derivative curve), the onset of thermal degradation was found to be 418.31^{o} C (785^{o} F) and the residual remaining weight was approximately 63% which would verify the 66% glass fiber in this duct material. The onset temperature indicates that the autoignition temperature for both these samples would be relatively high which also means good fire resistance.

The DSC's verified the findings of the TGA's but were not included because of the format of graphs.

ESTIMATED FIRE HEAT RELEASE RATES (HRR'S)

We attempted to calculate the heat release rate or rate of energy release (Figures 1.13, 2.13, 3.13, 4.13, 6.13, 9.13, 10.5, and 11.5) for each of the fires that were permitted to burn unimpeded which were ORNL 1.0 through ORNL 4.0 and ORNL 9.0 for the tank pit and ORNL 10.0, 11.0 for the cubicle tests. It is interesting to observe that although ORNL 1.0-3.0 are similar in maximum HRR they step down by about 200 KW from 1000 to 440 to 370 cfm respectively before they die from oxygen starvation. ORNL 4.0 which had the VOG duct installed illustrates how the duct work modified the airflow pattern causing the fire to burn longer at a HRR mostly between 600 and 800 KW. The data indicates that a fire of approximately 1.35 MW (Figure 1.13) is the maximum size fire before it extinguishes from oxygen starvation and this is without the FRP duct installed. The 2' x 4' opening between the tank pit and cubicle cell creates an airflow pattern that makes it difficult for oxygen to get down to sump floor and entrain into a developing fire.

On the other hand, for the cubicle tests (ORNL 10.0 and 11.0), the reduced air flow (10-16 cfm) and volume, and reduced quantity of kerosene produced fires of much lower HRR's. With the exception of a 270 KW spike before the flame went out in ORNL 11.0, the energy release rates stayed around 50 KW. It is not surprising that no fire damage was sustained by the FRP elbow out of the cubicle.

CONCLUSIONS

From the analysis of the results of this test series we can conclude the following:

1. That a fire in a tank pit of the ORNL REDC Bldg. 7920 will not cause the loss of ventilation system containment due to the thermal destruction and/or smoke breaching of the prefilters and HEPA filters. All burns demonstrated that there was no danger of the prefilters or HEPA's failing thermally, because the combustion gases had cooled down tremendously by the time they reached the filters. The maximum temperature at the prefilters was 70^{o}C in ORNL 9.0 which involved the flammable substrate with the Amercoat coating. Uninterrupted fires extinguished from lack of oxygen at all three tank pit ventilation rates. At the three airflows of 1000, 440, and 370 cfm, a 40 liter kerosene fire could not exist for more than a few minutes. From the ceiling view of the smoke generated by the burning kerosene, it can be seen that in a very short time visibility has been completely obscured by the combustion particulate. Even though this smoke was very dense, the prefilters and HEPA filters remained in service for multiple tests with excellent residual filtering capacities. This performance was certified by LLNL Industrial Hygienists who performed filter DOP penetration tests before and after each test. Their test results are included as Appendix A. As can be seen from Table 2, after 9 full scale tests the three HEPA filters had 38, 31, and 96 grams of particulate respectively, and an overall delta P of 0.7" of water. The roughing or prefilters after being through the final five tests had accumulated 224, 224, and 279 grams of particulate respectively and a delta P of 1.2" of water. Recall that these filters had been exposed to multiple kerosene fires, multiple sprinkler spray fires, and epoxy panel burns. These results are significant

because they show that the actual roughing and HEPA filters could be left in service for an extended period of time after a fire event.

2. Even if it were possible, a fire from a larger kerosene spill would not cause the breaching of the prefilters and HEPA filters. In fact, because of air flow pattern and quantity, a larger pool size would produce a bigger fire which would deplete the oxygen faster and, consequently, burn for a shorter period of time. Heat release rate data indicates that a fire of approximately 1.35 MW is the maximum size fire before it extinguishes from oxygen starvation. The 2' x 4' opening between the tank pit and cubicle pit creates an airflow pattern that makes it difficult for oxygen to get down to sump floor and entrain into a developing fire. Studying the oxygen and other gas concentrations at the 12' level (Figure 1.11) shows that there was adequate air at this level during the fire. Consequently, at the three tank pit airflows of 1000, 440, and 370 cfm, a 40 liter kerosene fire could not exist for more than a few minutes. Although they were rough measurements, in the majority of tests, less than 10 liters of kerosene was able to burn or evaporate from the post fire heat.

3. It would be nearly impossible to ignite a kerosene pool spilled on a tank pit or cubicle floor. We edited out the difficulties we had in igniting the 40 liter kerosene spills with a propane torch and paper wicks. In addition the series of electrical overload and arcing tests demonstrated that even at 200 amps of current, it was not possible to ignite the kerosene pool.

4. The VOG duct work will not ignite nor contribute to a tank pit fire. Under a number of worst case scenarios the duct did not ignite nor suffer any thermal damage, even though it was installed per Cell 3 specifications (positioning the horizontal run 3.5' above the fire) and was exposed to 5 tank pit fire tests. It was not surprising that the FRP ducting did as well is it did because its composition is more than 60% glass to under 40% epoxy. This means that a 60% of the duct material is non combustible.

5. A kerosene fueled fire in a cubicle would have no effect on the VOG FRP ventilation duct . The gas burner tests that placed the flame directly into the FRP elbow demonstrated that the interior of the VOG duct, even without the asbestos liner, would not ignite and contribute to the fire.The fire threat to the elbow is very low because of the small size of the fire, but more importantly, the lack of oxygen in the cubicle. This lack of ventilation flow causes the fire to not only extinguish in a short time, but it also cannot attain a high level of intensity. Post test inspection showed that there was no thermal damage to the elbow. This gas burner exposure was more severe than a fire fueled by sparse

quantities of polyethylene tubing, rags, and rubber gloves. Again, in the actual cubicle, the size of the fire would be greatly restricted by the scarce ventilation flow (~10-16 cfm).

6. Shutting off the inlet airflow to the tank pit almost immediately (within 1 minute) extinguished the fire: even at the 1000 cfm flow rate. This action would be a very effective fire suppression technique in the actual facility tank pits and cells.

7. Although the epoxy wall coating test was extremely unrealistic and severe, it demonstrated that even if the material could burn, it would have little or no thermal or smoke effect on the pre filters and HEPA filters. Thirty liters of kerosene and parts of the Wonder Board burned during this experiment. The polyamide cured epoxy coating did not ignite nor contribute to the fire, but did lose some of its binder or plasticizer from heating. Judging from these results, it is doubtful that the coating in the actual facility would ignite and sustain burning.

8. The fire detection and suppression system would respond quickly and efficiently. The HAD responded quickly and the sprinkler head knocked the fire down almost instantaneously. Sprinkler water vapor had no effect on the prefilters or HEPA filters. At approximately 20 gpm, as much as 100 gallons of water was sprayed into the tank pit during ORNL 8.0. However, as tests ORNL 1.0 thru ORNL 6.0 demonstrated, the sprinkler system could be used as a back up for shutting off the inlet ventilation flow in extinguishing fires. And even in the worst case without sprinkler intervention, with the ventilation running at 1000 cfm, the maximum fire burn time would be approximately 10 minutes. The filter system is more than capable of dealing with this worst case scenario.

9. Because these were full scale fire tests of the REDC tank pits, cells, and cubicles, the results are as realistic as can be practically achieved outside of actually setting fire to the facility. All these tests were set up and run conservatively. This fact makes the results even more reasonable. Even though the structures were dimensionally correct, the thermal properties of the building components and contents were much less than the actual structures. As mentioned previously, the tank pit, cell, and cubicle walls were a minmum of 2.0' thick concrete as opposed to the two layers of 5/8" thick gypsum wallboard used in the LLNL test articles. Full scale fire test results from a previous LLNL study [3] showed that approximately 80% of the thermal fluxes were absorbed by the concrete walls of the test cell. Although the LLNL test article was airtight, it was not as well sealed as the monolithically cast concrete cells and cubicles of the REDC facility. Although we were able to reproduce the ventilation rate through the tank pit and cubicle cell, our main exhaust provided less than half the dilution than the actual facility. In

addition, our filter system only provided half the number of filters than the actual system. Therefore, the containment ventilation system was exposed to twice the thermal and smoke assault it would experience in an actual fire situation. VOG ducts did not have the asbestos inner liner like the actual REDC duct work. It still did very well in the tests.

REFERENCES

[1] Alvares, N.J., "Analysis of Fire and Smoke Threat to Off-Gas HEPA Filters in a Transuranium Processing Plant," HC Dept., Annual Technology Review, 1987, Lawrence Livermore National Laboratory, UCRL-50007-87, Livermore, CA, July, 1988.

[2] King, L.J., et al, "Safety Analysis, Transuranium Processing Plant, Building 7920," ORNL/TM-7688 Draft, Oak Ridge National Laboratory, Oak Ridge, TN, December 1984.

[3] Hasegawa, H.K., Alvares, N.J., et al, "Fire Protection Research for DOE Facilities: FY 84 Year-End Report, Lawrence Livermore National Laboratory, UCRL-53179-84, Livermore, CA, September 1985.

ATTACHMENT 1

FP.3 PUBLIC PROTECTION

PERFORMANCE OBJECTIVE: All facilities onsite should provide adequate protection to prevent any added threat to the public as the result of an onsite fire causing the release of hazardous materials beyond the site (or facility) boundary.

FINDINGS:

- Credit is taken in building 7920 SAR for the cubicle and cell deluge fire sprinkler system. The sprinkler system is not designed as a safety class system.
- A preaction type sprinkler control valve, activated by heat detectors which are located in the cubicles and cells, controls water flow to the deluge valves.
- Deluge sprinkler systems protecting the cubicles are activated by manual means after workers either visually discover a fire or are warned of a fire by the cubicle fire detection system.
- The pneumatic and electric heat detectors which activate the preaction sprinkler system have not been tested since installation, there is no assurance that the detectors will work. One detector has been identified through continuity checks as being nonfunctional.
- This is the LLNL evaluation and designed to prove that a fire would not damage the HEPA filters used questionable and potentially nonconservative assumptions to reach the conclusion that a fire would not result in an unacceptable release.
- This concern was not identified in the ORNL Protective Services 1990 self-assessment.

CONCERN: (FP.3-2) (H1/C1) Documentation provided by Oak Ridge National Laboratory and DOE Headquarters does not support the conclusion that a fire originating in the cells or cubicles of building 7920 at the

CAT.II	Oak Ridge National Laboratory would not result in the loss of HEPA filters and an unacceptable radiological release to the environment.

FINDINGS:

- The SAR for building 7920 takes credit for manually and automatically operated sprinklers to successfully control fires which may occur within cells or cubicles. The sprinkler system is not designed as a safety class system, thus the system may not be available under all Design Basis Accident conditions.
- ORNL does not have an ongoing fire hazard analysis program.
- Each cubicle may contain up to approximately five liters of combustible liquids and each cell may contain up to 200 liters of combustible liquids.
- The Fire detection and suppression system for the cells and cubicles in building 7920 have not been tested in accordance with applicable National Fire Protection Agency standards.
- This concern was not identified in the ORNL Protective Services self-assessment plan. An action plan has not been developed.

CONCERN: (FP.3-1) (H1/C1) CAT. II	Oak Ridge National Laboratory has not tested, in accordance with recognized practices, the detection and suppression systems protecting cells and cubicles of building 7920 to assure that the devices will function as intended in the event of fire.

FINDINGS:

- HEPA filters at building 7920 are provided and are required to prevent an unacceptable radiation release to the environment.
- The building 7920 Safety Analysis Report takes credit for the sprinkler system for mitigating an in-cell or cubicle

fire such that it does not destroy the high efficiency particulate, air filters.

- The in-cell and cubicle 4 deluge sprinkler systems within building 7920 are not designed as safety class systems.

- Although the building 7920 SAR took credit for the in-cell and cubicle sprinklers operating limits had not been established which required the fire protection system to be operational.

- ORNL Fire Protection Engineering is not required to review and approve SARs.

- See also findings for Concerns FP.3-1 and FP.3-2.

- This concern was identified in the ORNL Protective Services self-assessment. An action plan has not been developed for its resolution.

CONCERN: (FP.3-3) (H2/C1)

Oak Ridge National Laboratory does not have a review program to assure that design basis fires within nuclear facilities site-wide will not result in an unacceptable release of radioactivity to the environment as required by DOE 5480.7.

TABLES

Test Matrix

TEST No.	Ventilation Flow Rate (CFM)			Sprinkler Operation		Comment
	Cell Inlet Air Flow Rate (CFM)	Total Exhaust Air Flow Rate(CFM)	Dilution Ratio	Start Time after ignition (sec)	Duration (sec)	
1.0	1060	3600	3.4:1			
2.0	440	3600	7.3:1			
3.0	370	3600	9.7:1			
4.0	1000	3600	3.6:1			VOG duct Installed
5.0	1000	3600	3.6:1			Inlet airflow shutoff at 280s from start of fire
6.0	440	3600	7.3:1			Inlet airflow shutoff at 140s from start of fire
7.0	1000	3600	3.6:1	380	120	
8.0	440	3600	7.3:1	145	300	
9.0	1000	3200	3.2:1			Epoxy coated panels installed
10.0						Cubicle fire test airflow set to 10-16 CFM
11.0						Cubicle fire test airflow set to 10-16 CFM
12.0						Cubicle VOG elbow fire test
12.1						Cubicle VOG elbow fire test

Table 1

Filter Loading

TEST No.	Pre filters					HEPA					
	TOP (grams)	MID (grams)	BOTTOM (grams)	TOTAL (grams)	ΔP (" of water)	TOP (grams)	MID (grams)	BOTTOM (grams)	TOTAL (grams)	ΔP (" of water)	GRAND TOTAL (grams)
1.0	54	55	70	179	1.5	19	21	28	68	1.0	247
2.0	31	39	27	97	1.6	-18*	-26*	-6*	-50*	0.9	47
3.0	29	34	23	86	2.0	3	-2	1	2	0.9	88
4.0	38	43	42	123	2.0	6	6	17	29	0.8	152
5.0**	30	24	31	85	0.2	-38*	-54*	-34*	-126*	0.9	-41*
6.0	35	34	46	115	0.6	-6*	-15*	-8*	-29*	1.0	86
7.0	21	36	25	82	0.8	13	18	16*	47	0.9	129
8.0	49	48	87	184	1.1	-17*	5	-4*	-16*	1.0	168
9.0	89	82	90	261	0.2	76	78	86	240	0.7	501
10.0											
11.0											
12.0											
12.1											

* Negative figure indicates that whatever loading was on these filters was volatile and evaporated away.
** New Pre filters were installed before test number 5.0

Table 2

Specifications

1. **Vessel Off-Gas (VOG) Ducts (specifications for actual REDC ducts):**

   - Bondstrand Pipe manufactured by Amercoat Corporation, Brea, CA.
   - Reinforced thermoset epoxy polymer.
   - Overall ratio of glass or asbestos reinforcement to resin, including liner: 66/34 to 75/25.
   - Type of pipe wall reinforcement: continuous glass filament wound.
   - 8" diameter in tank pit and 4" diameter in cubicle test.

2. **Epoxy Coating on Hot Cell Walls:**

   - System No. 1 Amercoat 66-3 with Thalco 1522 woven glass fiber.
   - Manufactured by Ameron Protective Coatings Division, Brea, CA.
   - High-build polyamide-cured epoxy coating, 30 mils thick.
   - Thalco 1522 woven glass fabric.

3. **Substrate for Epoxy Coated Panels:**

   - Wonder-Board backer board, Glascrete; manufactured by Glascrete, Inc., Seal Beach, CA.
   - Interior concrete board, with glass mesh 1/2" thick.
   - UL Listed 7L30.

4. **Sprinklers:**

   - Actual sprinklers in Bldg. 7920: Spray Engineering Model #GG8WA:
     - 120^o spray pattern.
     - Orifice size 23/64."
     - 22 gpm at 80 psi.
   - Sprinkler used in LLNL fire tests: Spraying Systems Co. Model #3/8HHSJ-12082, Spiraljet, Brass.
     - 120^o spray pattern.
     - Orifice size 3/8."
     - 20 gpm at 80 psi.

5. **Heat Actuated Detector (H.A.D.):**
   - Manufactured by Automatic Sprinkler Corporation of America.
   - The Thermal System Rate-of-Rise.
   - Approximate rate of rise 8 to 10^o C/min. (15 to 20^o F).
   - Thermal switches set at 80^o C (175^o F).

6. **Pre Filter and HEPA Filter Housing:** Two AstroSEAL 500 s. Each to house one wide, three high 24" x 24" x 11.5" filters.

7. **Roughing or Pre Filters (3):** Dustfoe Filter, B-2000, manufactured by Donaldson Co. Inc., Mpls, MN. ASHRAE efficiency: 90-95%. Metal housing 2' x 2' x 11-1/2".

8. **HEPA Filters (3):** Astrocel manufactured by American Air Filter, Louisville, KY. 1000 cfm, 99.99% efficiency. Plywood housing 2' x 2' x 11-1/2".

Table 3

CELL FIRE TESTS (20L FUEL SOURCE)

Test Series/Run		Initial Cell Air-flow (Inlet) (CFM)	Total Exh. Air-flow Rate (CFM)	Number HEPA Flt. 24X24X 11 1/2	Dilution Rate Fire Cell to total	Sprink. Operable During Test	Airflow Diff. P Monitor During Test	Temp. Monitored: Inlet Air to Cell	Temp. Monitored: Exh. Air lvg. Cell	Temp. Monitored: Pre-flt. Ent.	Temp. Monitored: HEPA flt. Ent.	Fuel Status: Burn until Con-sumed or Fire Ext.	Fuel Status: Weight res-idual fuel	Weight Filter Components: Before Test	Weight Filter Components: Imm. after Test	Weight Filter Components: Delayed after Test	DOP Test In-place leak test: Before	DOP Test In-place leak test: Aft
A	1	370	7310	3	19.8 to 1	No	Yes	X	X	X	X	X	X	X	X	X	X	X
	2	440	7310	3	16.6 to 1	No	Yes	X	X	X	X	X	X	X	X	X	X	X
	3	1000	7310	3	7.3 to 1	No	Yes	X	X	X	X	X	X	X	X	X	X	X
B	1	370	7310	3	19.8 to 1	Yes	Yes	X	X	X	X	X	X	X	X	X	X	X
	2	440	7310	3	16.6 to 1	Yes	Yes	X	X	X	X	X	X	X	X	X	X	X
	3	1000	7310	3	7.3 to 1	Yes	Yes	X	X	X	X	X	X	X	X	X	X	X
C	1	370*	7310**	3	19.8 to 1	Yes	Yes	X	X	X	X	X	X	X	X	X	X	X
	2	440*	7310**	3	16.6 to 1	Yes	Yes	X	X	X	X	X	X	X	X	X	X	X
	3	1000*	7310**	3	7.3 to 1	Yes	Yes	X	X	X	X	X	X	X	X	X	X	X
D	1	370	7310	3	19.8 to 1	Yes+	Yes	X	X	X	X	X		X	X	X	X	X
	2	440	7310	3	19.8 to 1	Yes+	Yes	X	X	X	X	X		X	X	X	X	X
	3	1000	7310	3	7.3 to 1	Yes+	Yes	X	X	X	X	X		X	X	X	X	X

X = Yes
* - Zero after rate-of-rise alarm is actuated ** reduced rate if fire cell inlet air damper closes
+ - Deliberately operated to simulate unintentional release of water

Table 4: Preliminary Test Matrix

FIGURES

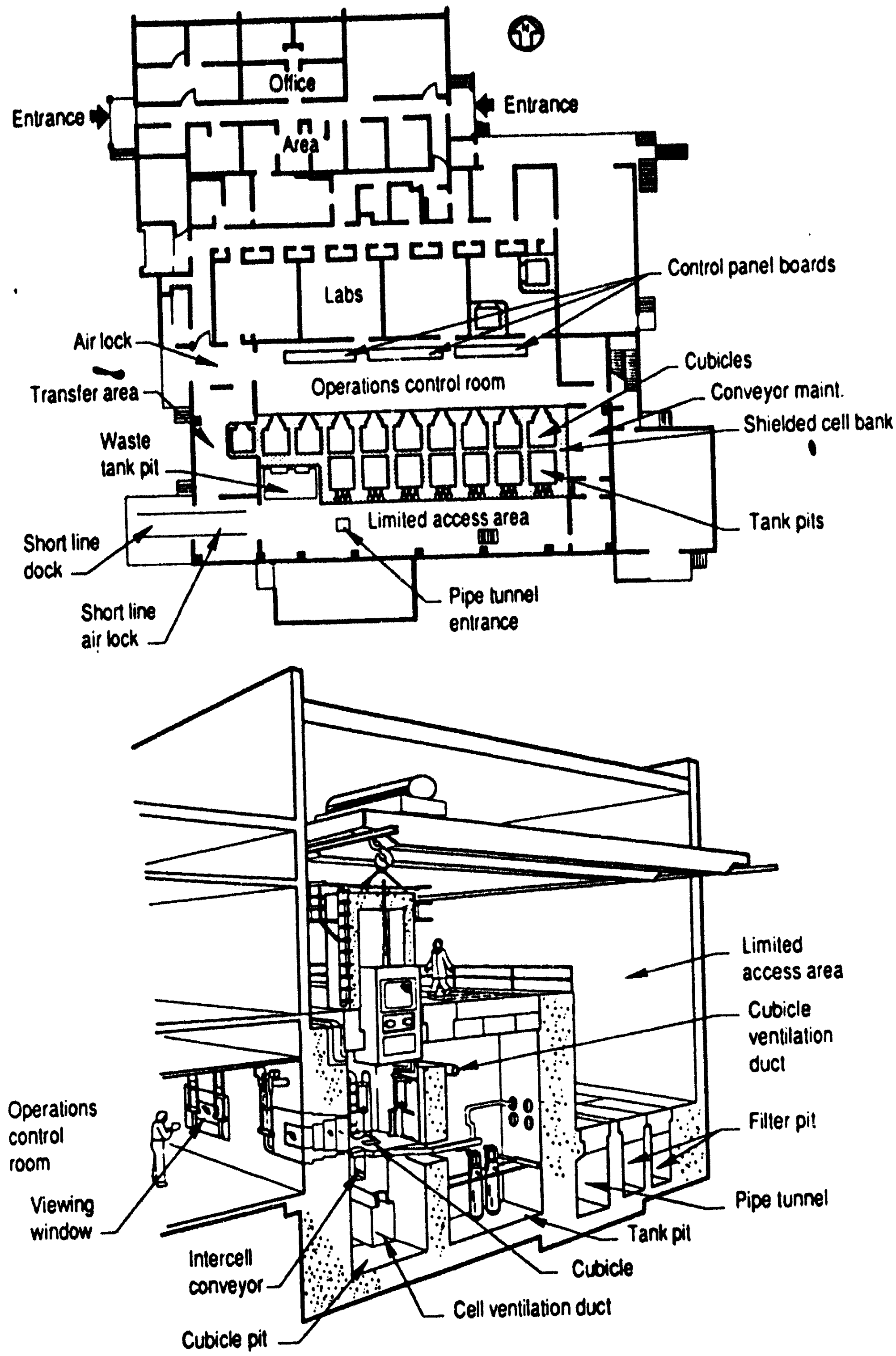
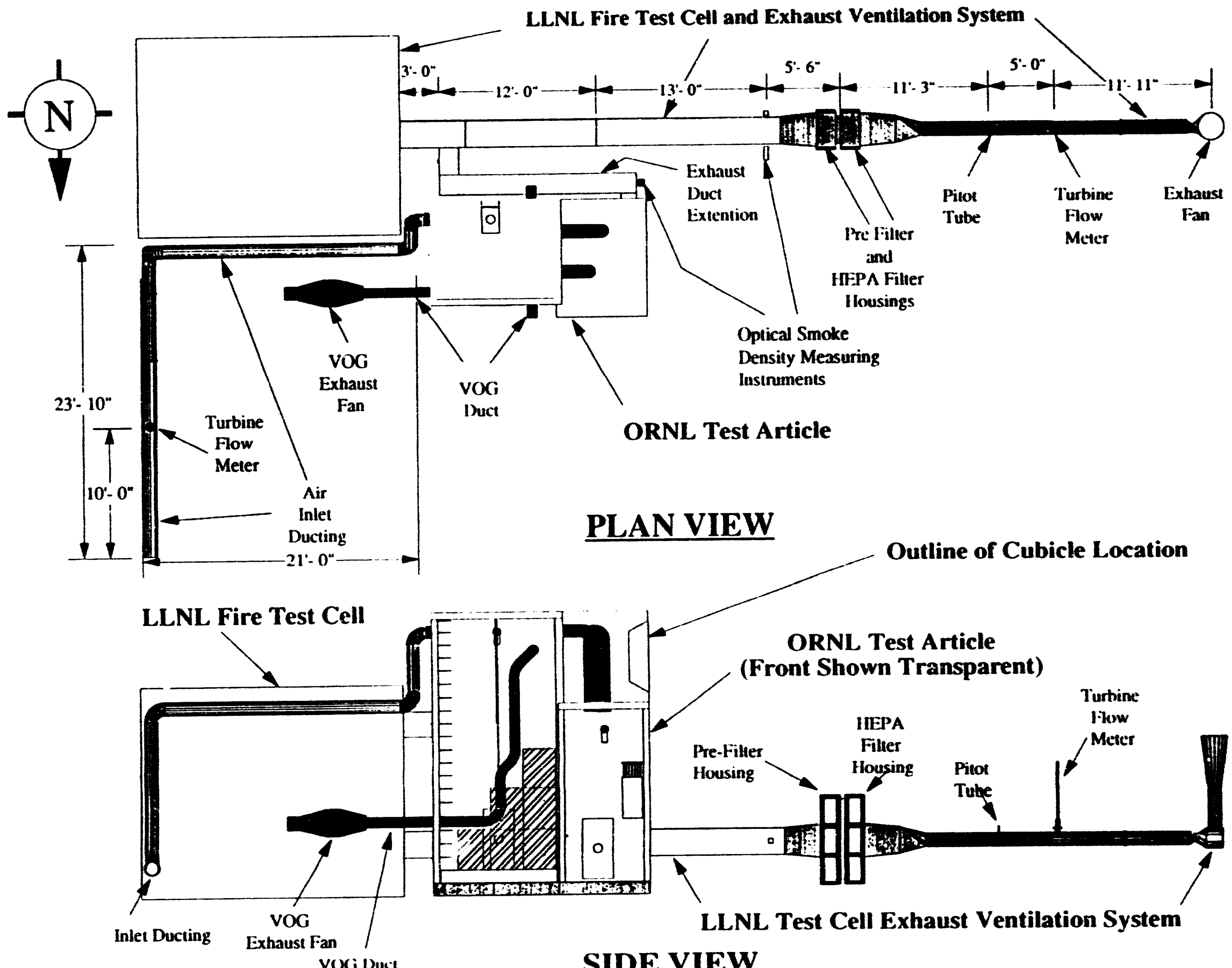
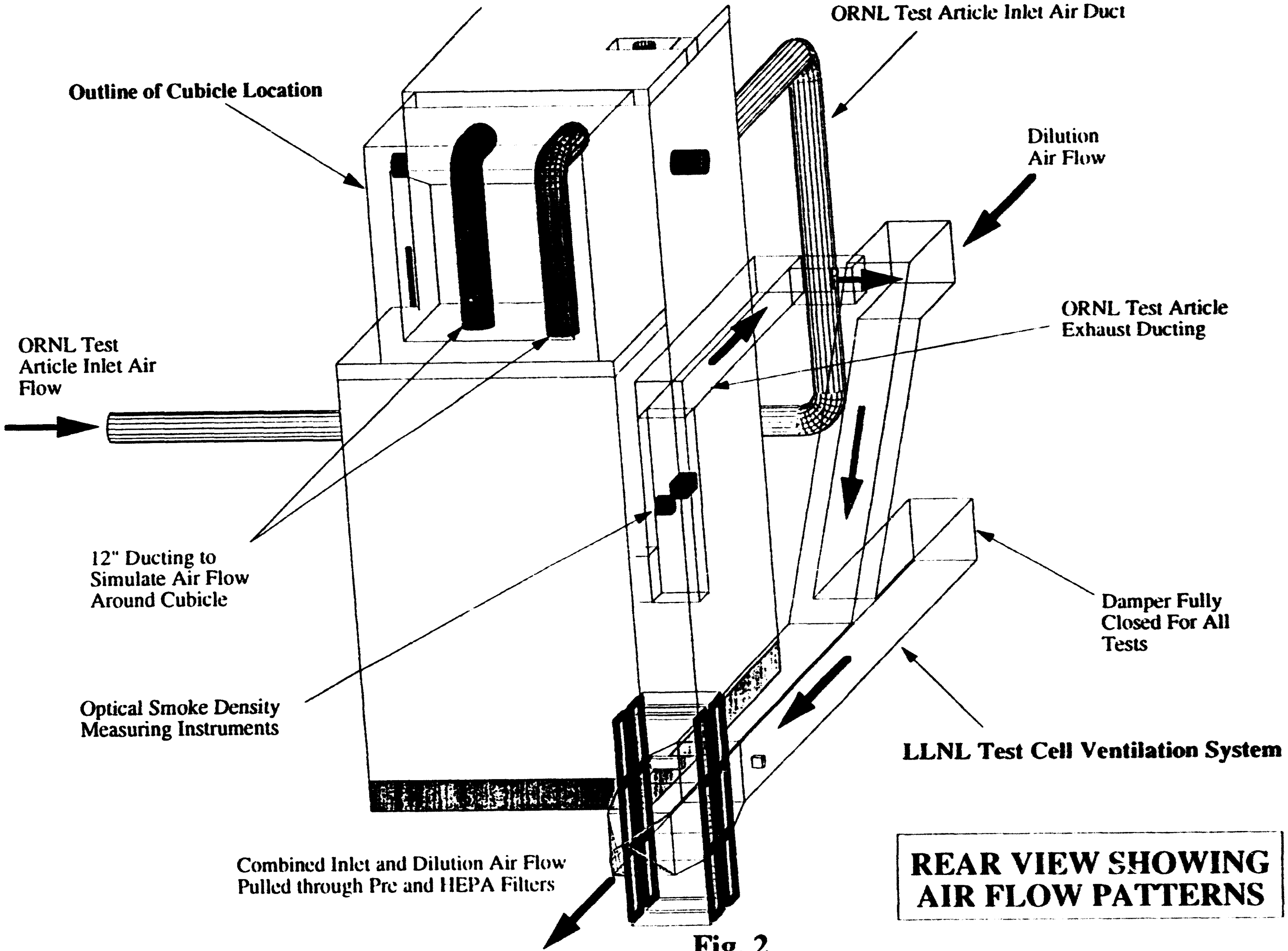


Figure N-1. Plan of the transuranium processing plant (top) and isometric view of a typical cell (bottom).



LLNL Fire Test Cell and Exhaust Ventilation System
N
3'- 0"
12'- 0"
13'- 0"
5'- 6"
11'- 3"
5'- 0"
11'- 11"
Exhaust Duct Extention
Pitot Tube
Turbine Flow Meter
Exhaust Fan
Pre Filter and HEPA Filter Housings
Optical Smoke Density Measuring Instruments
VOG Exhaust Fan
VOG Duct
ORNL Test Article
23'- 10"
10'- 0"
Turbine Flow Meter
Air Inlet Ducting
21'- 0"
PLAN VIEW
Outline of Cubicle Location
LLNL Fire Test Cell
ORNL Test Article (Front Shown Transparent)
Turbine Flow Meter
HEPA Filter Housing
Pre-Filter Housing
Pitot Tube
Inlet Ducting
VOG Exhaust Fan
VOG Duct
LLNL Test Cell Exhaust Ventilation System
SIDE VIEW

FIG. 1



ORNL Test Article Inlet Air Duct
Outline of Cubicle Location
Dilution Air Flow
ORNL Test Article Exhaust Ducting
ORNL Test Article Inlet Air Flow
12" Ducting to Simulate Air Flow Around Cubicle
Damper Fully Closed For All Tests
Optical Smoke Density Measuring Instruments
LLNL Test Cell Ventilation System
Combined Inlet and Dilution Air Flow Pulled through Pre and HEPA Filters
REAR VIEW SHOWING AIR FLOW PATTERNS

Fig. 2

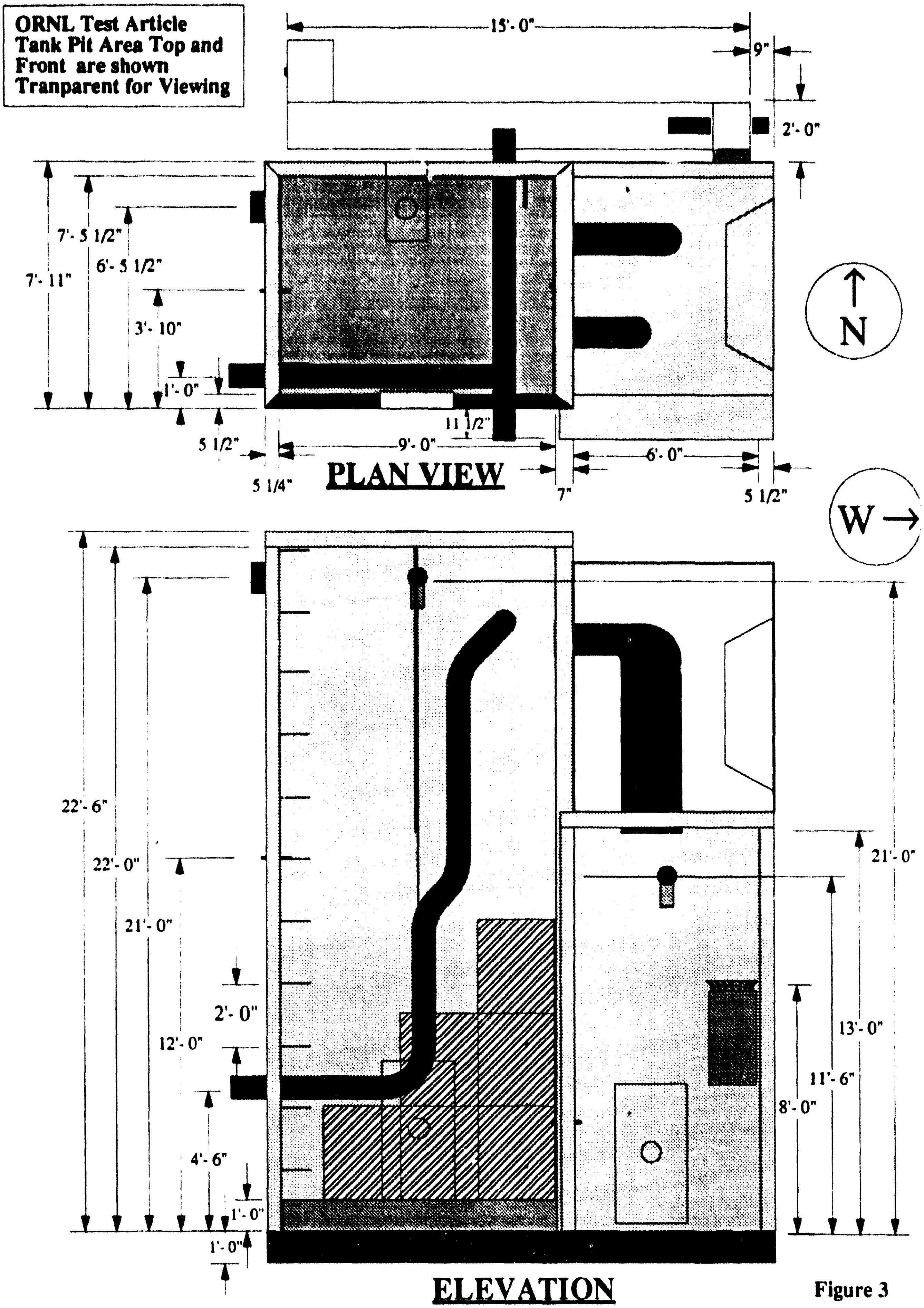

ORNL Test Article
Tank Pit Area Top and
Front are shown
Tranparent for Viewing
15'- 0"
9"
2'- 0"
7'- 11"
7'- 5 1/2"
6'- 5 1/2"
3'- 10"
1'- 0"
5 1/2"
5 1/4"
9'- 0"
11 1/2"
7"
6'- 0"
5 1/2"
N
W
PLAN VIEW
22'- 6"
22'- 0"
21'- 0"
12'- 0"
2'- 0"
4'- 6"
1'- 0"
1'- 0"
21'- 0"
13'- 0"
11'- 6"
8'- 0"
ELEVATION

Figure 3

PRIMARY VENTILATION FLOW

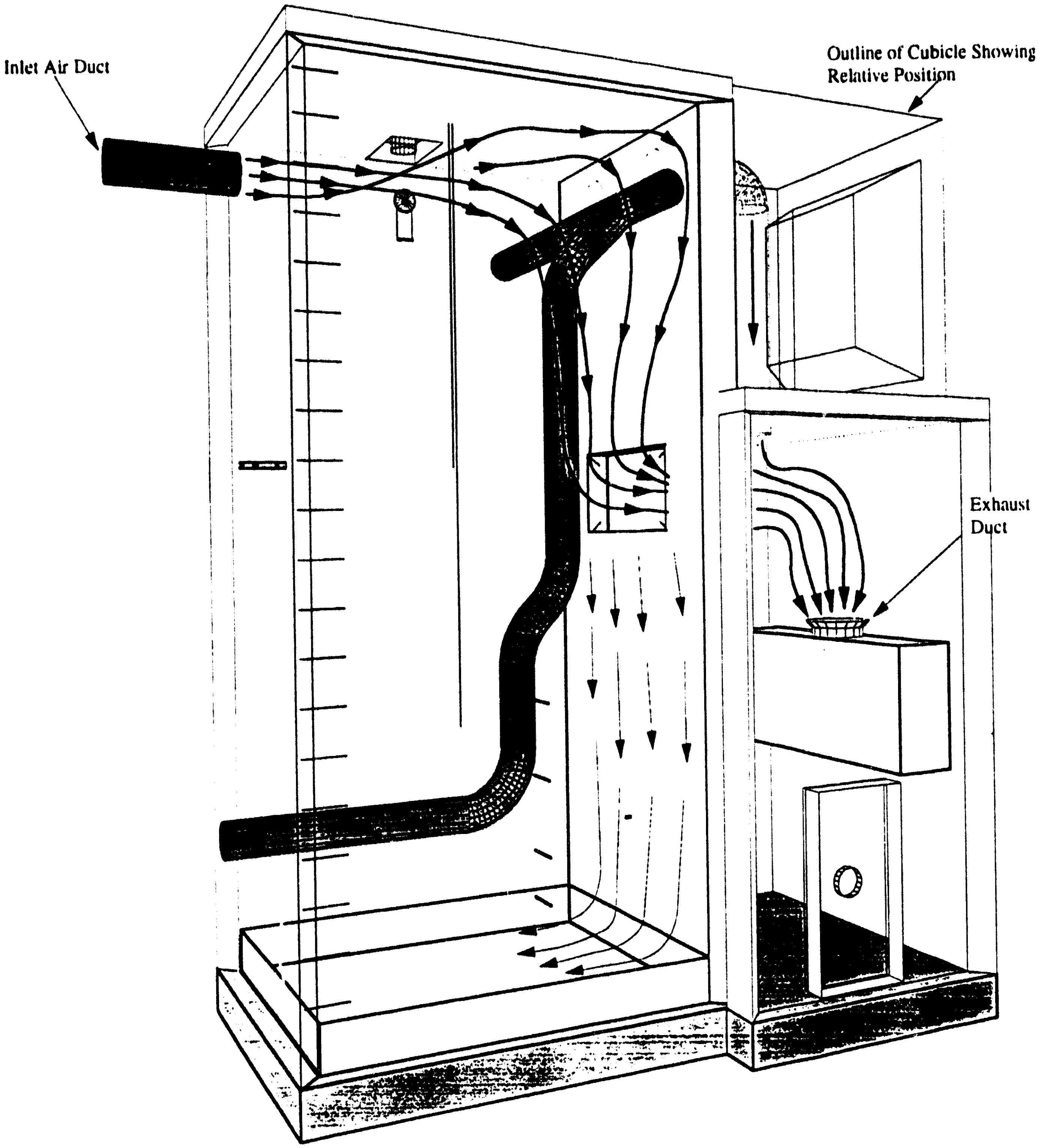


FIG. 4

VIEW SHOWING DETAIL OF INSTRUMENTATION

(Front And Side Walls Made Transparent For Viewing)

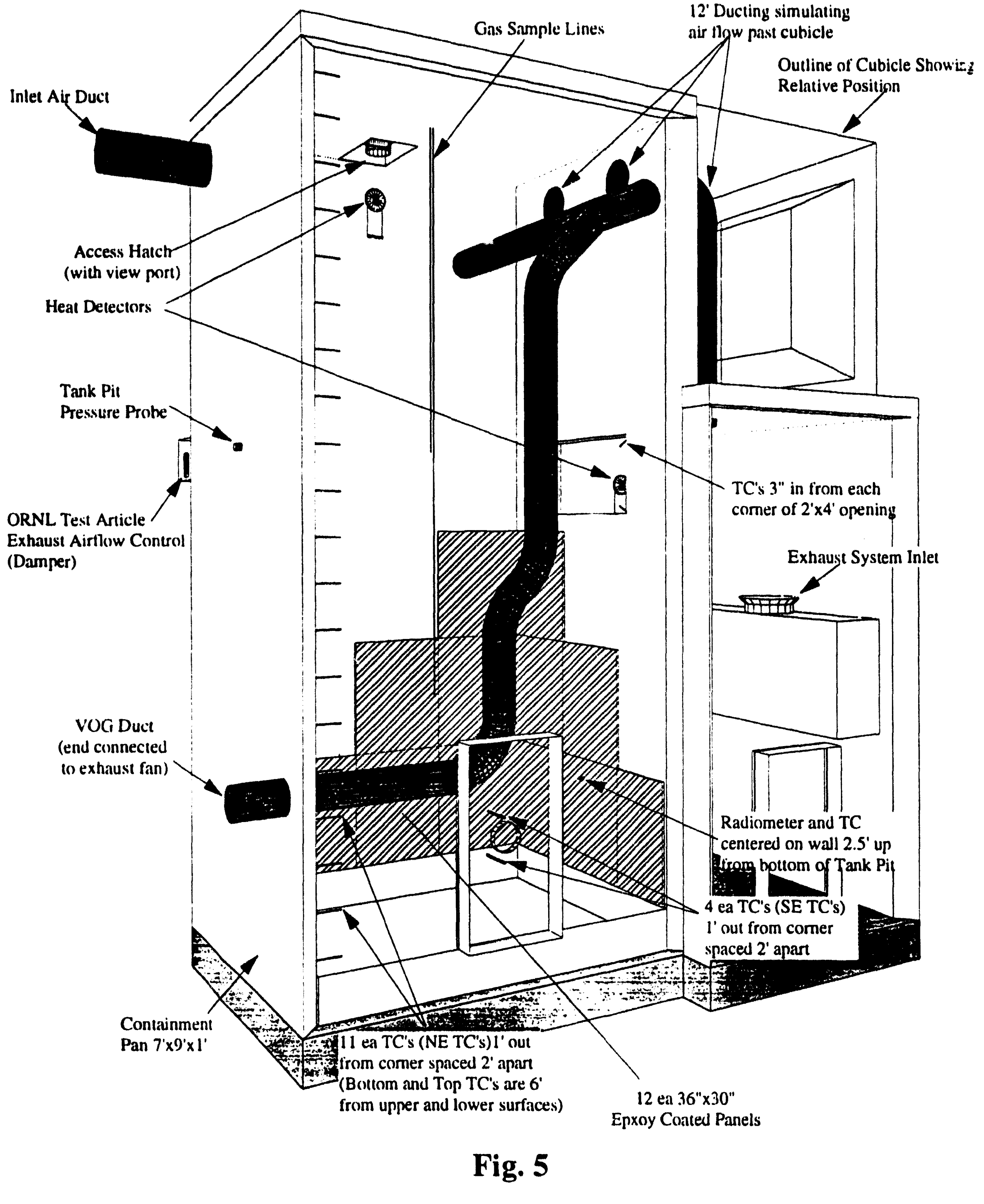


Fig. 5

VIEW SHOWING DETAIL OF INSTRUMENTATION IN CUBICLE

(Front And Side Walls Made Transparent For Viewing)

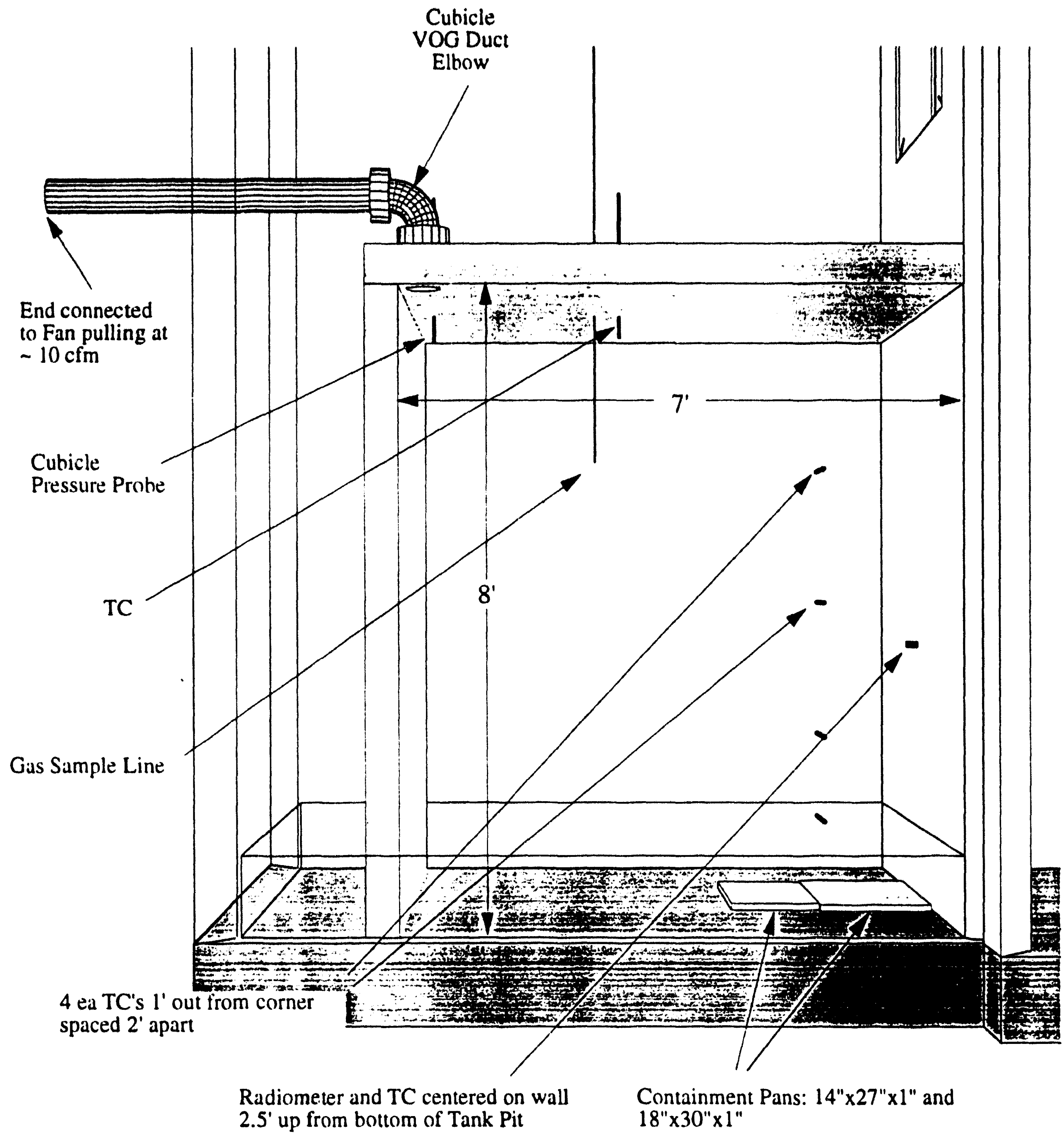


Fig . 6

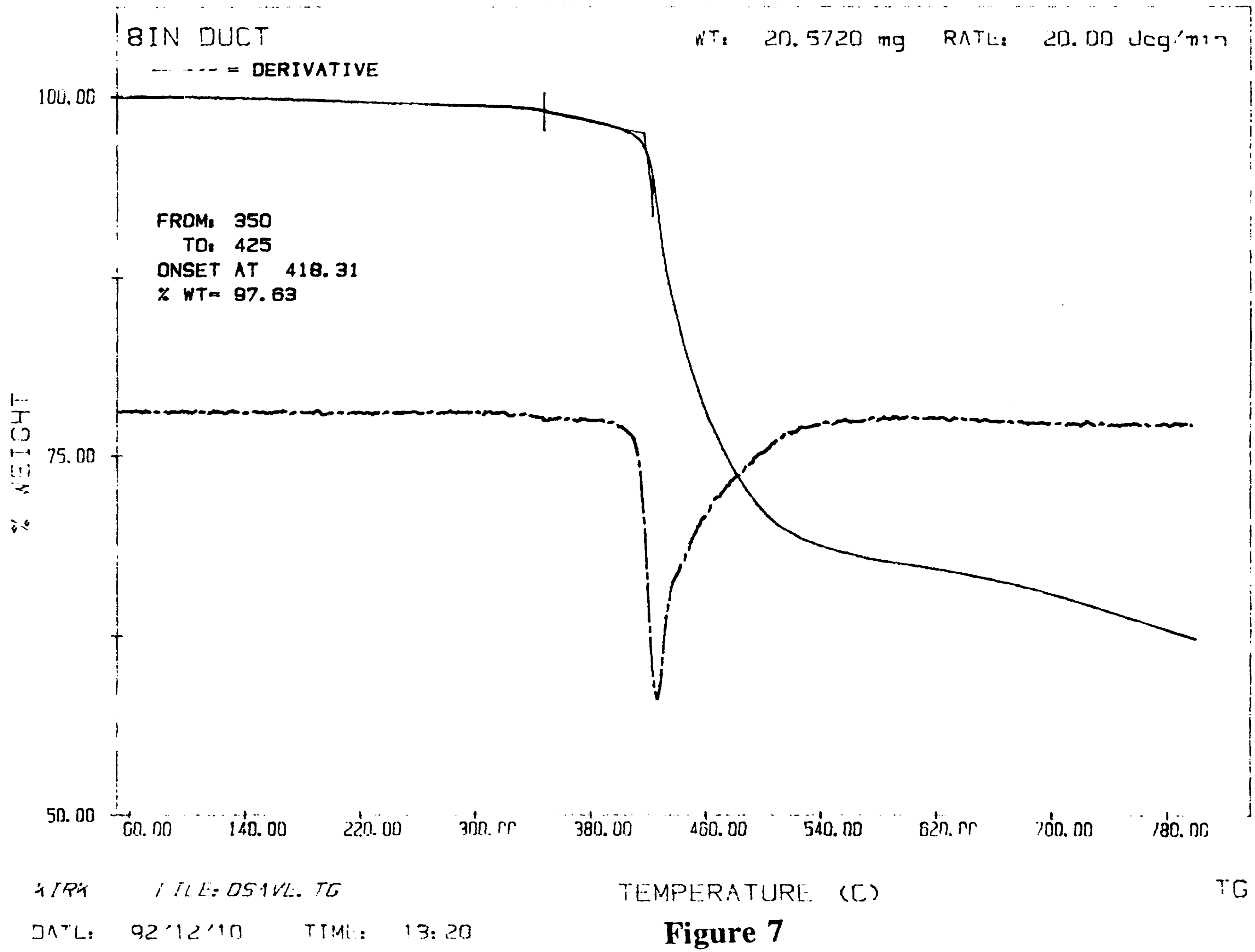
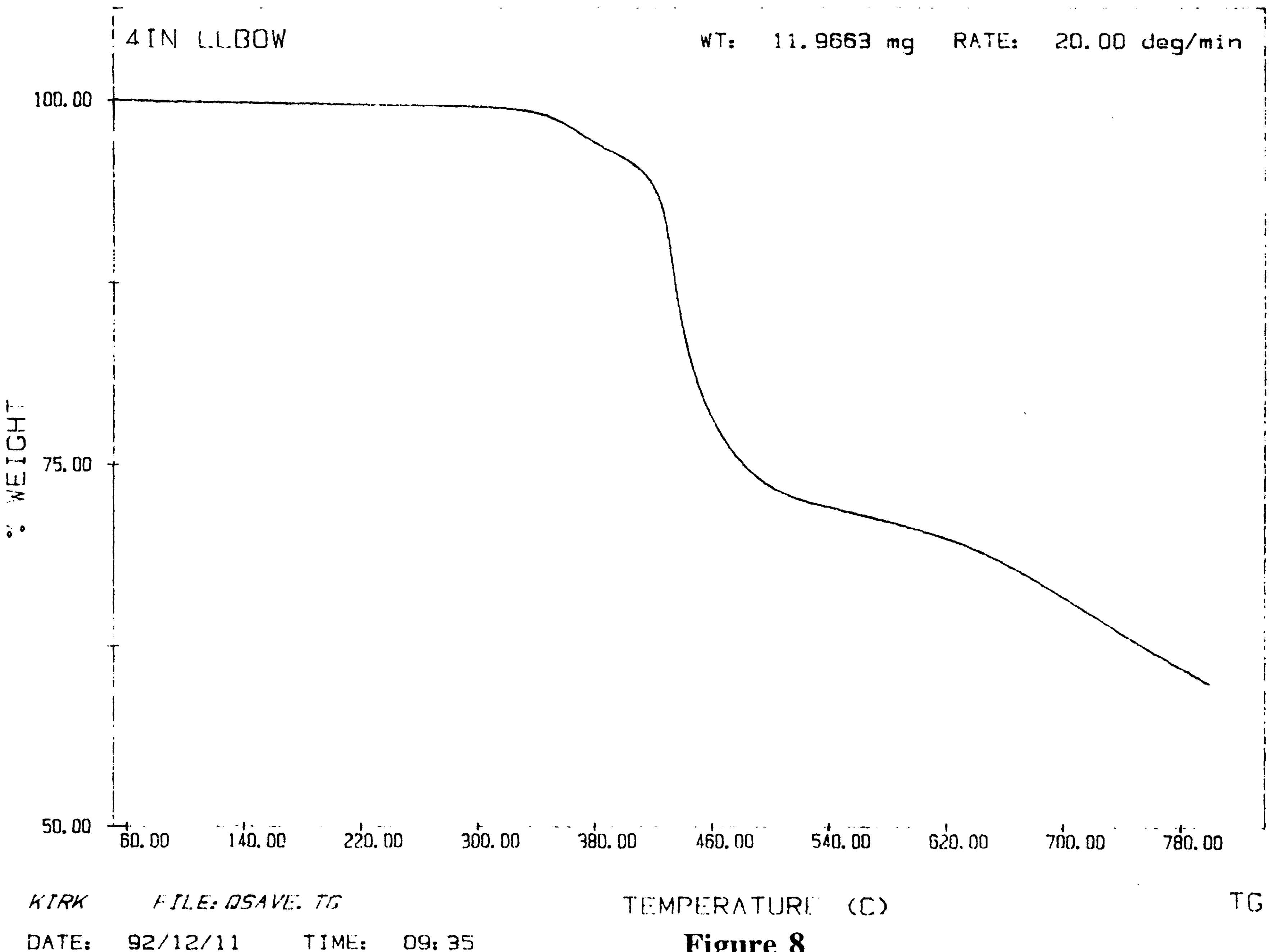

8IN DUCT
WT: 20.5720 mg RATE: 20.00 deg/min
---- = DERIVATIVE
FROM: 350
TO: 425
ONSET AT 418.31
% WT= 97.63
100.00
75.00
50.00
% WEIGHT
60.00
140.00
220.00
300.00
380.00
460.00
540.00
620.00
700.00
780.00
TEMPERATURE (C)
FILE: DS1VL.TG
TG
DATE: 92/12/10 TIME: 13:20

Figure 7



4IN LLBOW
WT: 11.9663 mg RATE: 20.00 deg/min
100.00
75.00
50.00
% WEIGHT
60.00
140.00
220.00
300.00
380.00
460.00
540.00
620.00
700.00
780.00
KIRK FILE: QSAVE. TG
TEMPERATURE (C)
TG
DATE: 92/12/11 TIME: 09:35

Figure 8

APPENDIX A

L-442 ORNL 1.0

TO: [redacted]/Scott Doty

HAZARDS CONTROL — INDUSTRIAL HYGIENE INSTRUMENT LAB
HEPA FILTER TEST RESULTS

PAGE 1 OF 1

BLDG.: 328 Test: ORNL 1.0

TEST/VISIT DATE 6/17/92 & 6/18/92

FILTER NO.	LOCATION	FAN NO.	PERCENT EFFICIENCY	ΔP in. H_2O	FILTER SIZE (CFM)	TEAM	DUE DATE	INSTALL. DATE	DUCT SIZE	VELOCITY (FPM)	CFM
n/a	B/328	none	99.99	1.0	1000	n/a	n/a				

REMARKS: 6/17/92: Performed another aerosol test of the in-place HEPA filter system for ORNL 1.0. Same test procedures used as in previous tests for the ORNL 1.0 project. Results were 99.99% efficiency on the filter system. This test was performed just before a test burn.

6/18/92: Aerosol test was performed after burn test on 6/17. Filter efficiency was 99.99%. Filters were removed immediatel after HEPA test and weighed and reinstalled and another HEPA test performed immediately after reinstallation. Results were 99.99% efficiency.

cc: Bruce Bettencourt; H. Hasegawa

SIGNED: Jan Elliott / Jim Boyer EXT. 34221

L-442 ORNL 2.0

HAZARDS CONTROL — INDUSTRIAL HYGIENE INSTRUMENT LAB
HEPA FILTER TEST RESULTS

TO: Kirk Staggs/Scott Doty

BLDG.: 328 Test: ORNL 1.0

TEST/VISIT DATE 6/17/92 & 6/18/92

FILTER NO.	LOCATION	FAN NO.	PERCENT EFFICIENCY	ΔP in. H_2O	FILTER SIZE (CFM)	TEAM	DUE DATE	INSTALL. DATE	DUCT SIZE	VELOCITY (FPM)	CFM
n/a	B/328	none	99.99	1.0	1000	n/a	n/a				

REMARKS: 6/17/92: Performed another aerosol test of the in-place HEPA filter system for ORNL 1.0. Same test procedures used as in previous tests for the ORNL 1.0 project. Results were 99.99% efficiency on the filter system. This test was performed just before a test burn.
6/18/92: Aerosol test was performed after burn test on 6/17. Filter efficiency was 99.99%. Filters were removed immediately after HEPA test and weighed and reinstalled and another HEPA test performed immediately after reinstallation. Results were 99.99% efficiency.

cc: Bruce Bettencourt; H. Hasegawa

SIGNED: Jim Elliott / Jim Boyer EXT. 34221

IL 5531 (Rev. 2-..)

DLNV 2.0

TO: Kirk Staggs

BLDG.: 328

HAZARDS CONTROL — INDUSTRIAL HYGIENE INSTRUMENT LAB
HEPA FILTER TEST RESULTS

PAGE 1 OF 1

TEST/VISIT DATE 6/17/93

FILTER NO.	LOCATION	FAN NO.	PERCENT EFFICIENCY	Δ P in. H_2O	FILTER SIZE (CFM)	TEAM	DUE DATE	INSTALL. DATE	DUCT SIZE	VELOCITY (FPM)	CFM
–	B 328	–	99.99	1.0	[illegible]						

REMARKS: Post Fire Test.

CC: B. Bettencourt, H. Hasegawa

SIGNED: [illegible]

EXT. 36551

ORNL 3.0

TO: Rick [redacted]

BLDG.: 328

HAZARDS CONTROL — INDUSTRIAL HYGIENE INSTRUMENT LAB
HEPA FILTER TEST RESULTS

PAGE 1 OF 1

TEST/VISIT DATE 6/22/92 A.M.

FILTER NO.	LOCATION	FAN NO.	PERCENT EFFICIENCY	ΔP in. H_2O	FILTER SIZE (CFM)	TEAM	DUE DATE	INSTALL. DATE	DUCT SIZE	VELOCITY (FPM)	CFM
–	B/328	NONE	99.99	1.0	1000	-	–	–	-		

REMARKS: FILTERS WERE REMOVED & WEIGHED AFTER THE BURN ON 6/19/92. THE TEST TODAY IS FOR THE PRE-ORNL 3.0 TEST.

CC: B. BETTENCOURT, H. HASEGAWA

SIGNED: Jim Ellis / Jim Boyer

EXT. 34821 / 36551

11 5531 (Rev. 2/92)

ORNL 3.0

TO: [redacted] STAGGS

HAZARDS CONTROL — INDUSTRIAL HYGIENE INSTRUMENT LAB
HEPA FILTER TEST RESULTS

PAGE 1 OF 1

BLDG.: 328

TEST/VISIT DATE 6/23/92

FILTER NO.	LOCATION	FAN NO.	PERCENT EFFICIENCY	ΔP in. H_2O	FILTER SIZE (CFM)	TEAM	DUE DATE	INSTALL. DATE	DUCT SIZE	VELOCITY (FPM)	CFM
–	328 PRE-WEIGH	–	99.99	1.0	1000	–	–	–			
–	328 POST WEIGH	–	99.99	1.0	1000						

REMARKS:

cc: B. Bettencourt, H. Hasegawa

SIGNED: [signature]

EXT. 34921

UI-5531 (Rev. 2/92)

ORNL 4.0

TO: Mike Stages

BLDG.: 328

HAZARDS CONTROL — INDUSTRIAL HYGIENE INSTRUMENT LAB
HEPA FILTER TEST RESULTS

PAGE 1 OF 1

TEST/VISIT DATE 6/23/92

FILTER NO.	LOCATION	FAN NO.	PERCENT EFFICIENCY	ΔP in. H_2O	FILTER SIZE (CFM)	TEAM	DUE DATE	INSTALL. DATE	DUCT SIZE	VELOCITY (FPM)	CFM
-	328 PRE-WEIGH	-	99.99	1.0	1000	-	-	-			
-	328 POST WEIGH	-	99.99	1.0	1000						

REMARKS:

cc: B. Bettencourt, H. Nakagawa

SIGNED: [illegible]

EXT. 34821

IL-5531 (Rev. 2/92)

TO: Kirk Staggs/S. Doty

BLDG.: 328

HAZARDS CONTROL — INDUSTRIAL HYGIENE INSTRUMENT LAB
HEPA FILTER TEST RESULTS ORNL 4.0

PAGE 1 OF 1

TEST/VISIT DATE 7/7/92

FILTER NO.	LOCATION	FAN NO.	PERCENT EFFICIENCY	ΔP in. H_2O	FILTER SIZE (CFM)	TEAM	DUE DATE	INSTALL. DATE	DUCT SIZE	VELOCITY (FPM)	CFM
–	B/328	None	99.99	1.0	1000	–	N/A	–	Flow taken by K. Staggs		

REMARKS: Post Burn - ORNL 4.0

cc: B. Bettencourt, [redacted]

SIGNED: [signature] / Jim Boyer

EXT. 34821
36351

ORNL 5.0

TO: [redacted] HAZARDS CONTROL — INDUSTRIAL HYGIENE INSTRUMENT LAB

HEPA FILTER TEST RESULTS

PAGE 1 OF 1

BLDG.: 328

TEST/VISIT DATE 7/15/92

FILTER NO.	LOCATION	FAN NO.	PERCENT EFFICIENCY	Δ P in. H_2O	FILTER SIZE (CFM)	TEAM	DUE DATE	INSTALL. DATE	DUCT SIZE	VELOCITY (FPM)	CFM
—	328	NONE	99.99	0.9	1000	—	—	—	—		
System test of 3 HEPA Flts.											

REMARKS: ORNL 5.0 PREBURN

cc: B. Betencourt, H. Hasegawa

SIGNED: Jan Elliott / Jim Boyer

EXT. 34821
36557

TO: KIRK STAGGS / S.M. DOUGHTY

ORNL 5.0

HAZARDS CONTROL — INDUSTRIAL HYGIENE INSTRUMENT LAB
HEPA FILTER TEST RESULTS

BLDG.: 328

TEST/VISIT DATE July 15 1992

FILTER NO.	LOCATION	FAN NO.	PERCENT EFFICIENCY	ΔP in. H_2O	FILTER SIZE (CFM)	TEAM	DUE DATE	INSTALL. DATE	DUCT SIZE	VELOCITY (FPM)	CFM
ORNL 5 POST TEST (1)	B.328	–	99.99	0.9	1000	–	–	–	–		
ORNL 6 PRE-TEST	B-328		99.99	1.0							
ORNL 6 POST TEST (1)	B-328		99.99	1.0							
ORNL 7 POST TEST (2)	B-328		99.99	1.0							

REMARKS: (1) = BEFORE WEIGHING HEPAs.
(2) = AFTER WEIGHING HEPAs.

cc: BRUCE BETTENCOURT, HARRY HASEGAWA

SIGNED: [signature]

EXT. 36551

LL 5531 (Rev. 2/92)

ORNL 6.0

TO: KIRK STAGGS / S.M. DOUGHTY

HAZARDS CONTROL — INDUSTRIAL HYGIENE INSTRUMENT LAB

HEPA FILTER TEST RESULTS

BLDG.: 328

TEST/VISIT DATE July 15 1992

FILTER NO.	LOCATION	FAN NO.	PERCENT EFFICIENCY	ΔP in. H_2O	FILTER SIZE (CFM)	TEAM	DUE DATE	INSTALL. DATE	DUCT SIZE	VELOCITY (FPM)	CFM
ORNL 5 POST TEST ②	B.328	–	99.99	0.9	1000	–	–	–	–		
ORNL 6 PRE-TEST	B-328		99.99	1.0							
ORNL 6 POST TEST ①	B-328		99.99	1.0							
ORNL 7 POST TEST ②	B-328		99.99	1.0							

REMARKS: ① = BEFORE WEIGHING HEPAs.
② = AFTER WEIGHING HEPAs.

CC: BRUCE BETTENCOURT, HARRY HASEGAWA

SIGNED: Jim Boggs

EXT. 36551

IL 5531 (Rev. 2/92)

ORNL 7.0

TO: [redacted]

BLDG.: 328

HAZARDS CONTROL — INDUSTRIAL HYGIENE INSTRUMENT LAB

HEPA FILTER TEST RESULTS

PAGE 1 OF 1

TEST/VISIT DATE (1&2) 7/16/92 / (3) 7/17/92

	FILTER NO.	LOCATION	FAN NO.	PERCENT EFFICIENCY	ΔP in. H_2O	FILTER SIZE (CFM)	TEAM	DUE DATE	INSTALL. DATE	DUCT SIZE	VELOCITY (FPM)	CFM
1)	-	B/328	-	99.99	1.0	1000	-	-	-	-		
2)	-	"	-	99.99	1.0	"	-	-	-	-		
3)		"		99.99	0.9	"	-	-	-	-		

REMARKS: ① POST-ORNL 7.0 - FILTERS WEIGHED & RE-INSTALLED. (PREFILT. + HEPAS).

② PRE-ORNL 8.0

③ POST ORNL 8.0

CC: B. BERGENCOURT / H. HASEGAWA

SIGNED: [illegible] / [illegible] EXT. 34821 36551

ORNL 7.0

TO: KIRK STAGGS / S.M. DOUGHTY

HAZARDS CONTROL — INDUSTRIAL HYGIENE INSTRUMENT LAB
HEPA FILTER TEST RESULTS

BLDG.: 328

TEST/VISIT DATE July 15 1992

FILTER NO.	LOCATION	FAN NO.	PERCENT EFFICIENCY	ΔP in. H_2O	FILTER SIZE (CFM)	TEAM	DUE DATE	INSTALL. DATE	DUCT SIZE	VELOCITY (FPM)	CFM
ORNL 5 POST TEST ①	B.328	–	99.99	0.9	1000	–	–	–	–		
ORNL 6 PRE-TEST	B.328	↓	99.99	1.0	↓	↓	↓	↓	↓		
ORNL 6 POST TEST ①	B-328		99.99	1.0							
ORNL 7 POST TEST ②	B-328		99.99	1.0							

REMARKS: ① = BEFORE WEIGHING HEPAs.
② = AFTER WEIGHING HEPAs.

SIGNED: Jim B[illegible] EXT. 36551

cc: BRUCE BETTENCOURT, HARRY HASEGAWA

LL 5531 (Rev 2/92)

ORNL 8.0

TO: Kirk Staggs / Scott Doughty

HAZARDS CONTROL — INDUSTRIAL HYGIENE INSTRUMENT LAB
HEPA FILTER TEST RESULTS

PAGE 1 OF 1

TEST/VISIT DATE (1&2) 7/16/92 (3) 7/17/92

BLDG.: 328

	FILTER NO.	LOCATION	FAN NO.	PERCENT EFFICIENCY	ΔP in. H_2O	FILTER SIZE (CFM)	TEAM	DUE DATE	INSTALL. DATE	DUCT SIZE	VELOCITY (FPM)	CFM
(1)	-	B/328	-	99.99	1.0	1000	-	-	-	-		
(2)	-	"	-	99.99	1.0	"	-	-	-	-		
(3)		"		99.99	0.9	"	-	-	-	-		

REMARKS: (1) POST-ORNL 7.0 - FILTERS WEIGHED & RE-INSTALLED. (PREFILT. & HEPAS).

(2) PRE-ORNL 8.0

(3) POST ORNL 8.0

SIGNED: [signatures] EXT. 34821

CC: B. Berencourt / H. Hasegawa

ORNL 9.0

TO: Kirk Staggs/S. Dougherty

HAZARDS CONTROL — INDUSTRIAL HYGIENE INSTRUMENT LAB
HEPA FILTER TEST RESULTS

PAGE 1 OF 1

10/13/92 ORNL 9.0

TEST/VISIT DATE 10/14/92

BLDG.: 328

~~FILTER~~ S NO.	LOCATION	FAN NO.	PERCENT EFFICIENCY	ΔP in. H_2O	FILTER SIZE (CFM)	TEAM	DUE DATE	INSTALL. DATE	DATE ~~DUCT SIZE~~	~~VELOCITY~~ (~~FPM~~)	~~CFM~~
ORNL 9.0	B/328	—	99.99	THIS	1000	—	—		10/13/92		
PRETEST	(PREBURN)			ΔP INFO.							
				WAS							
ORNL 9.0 POST TEST	"	—	99.99	RECORDED	"	—	—		10/14/92		
(POSTBURN)				BY							
				FIRE SCIENCE							
				PERSONNEL.							

REMARKS: TEST PROCEDURE IS SAME AS DONE FOR ALL PREVIOUS ORNL HEPA TESTS.
THIS CONCLUDES THE HEPA TESTING FOR THE ORNL PROJECT.

SIGNED: [signature] EXT. 34821

cc: B. Berkenkamp / H. Hasegawa

IH-5531 (Rev. 2/92)

PHOTOS

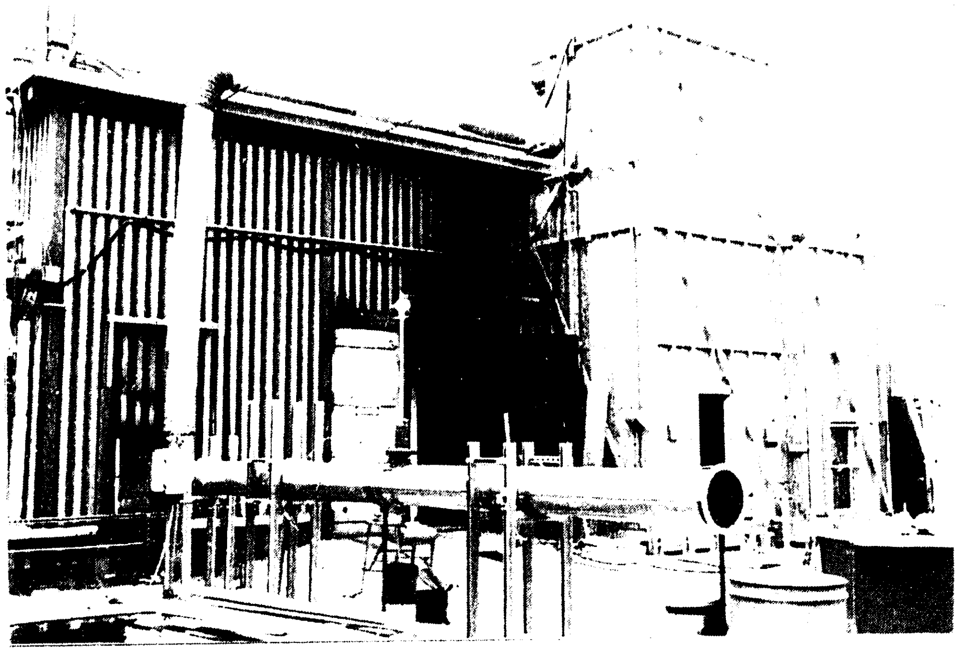


Photo 1 : Overall view of test article with inlet duct

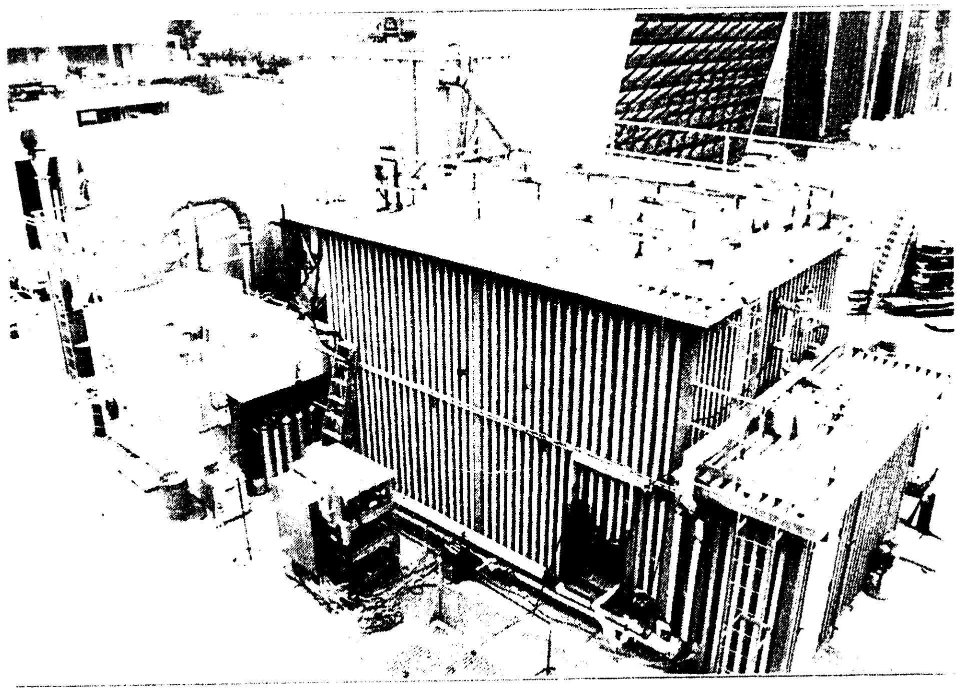


Photo 2 : Overall view of L.L.N.L. fire test facilty

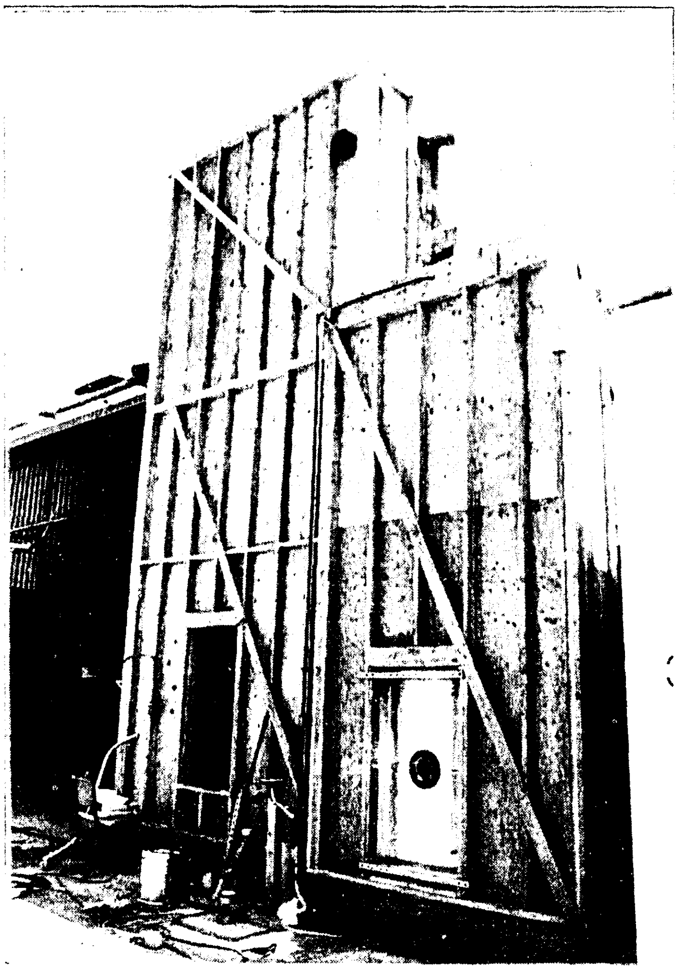


Photo 3 : Close-up of O.R.N.L. test enclosures.

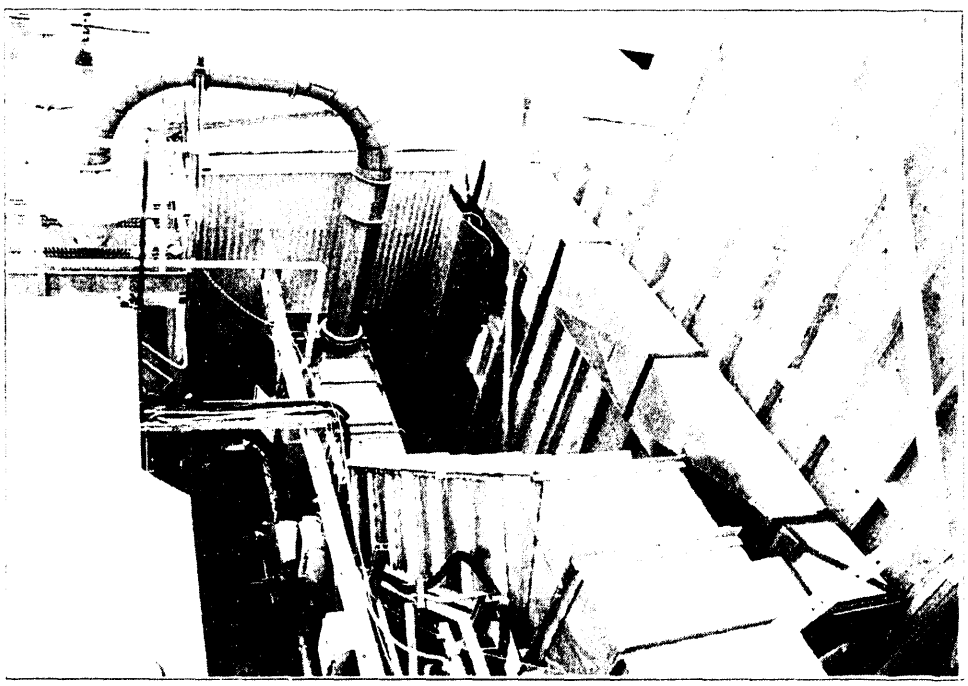


Photo 4 : Detail of COG exhaust duct out of cubicle cell

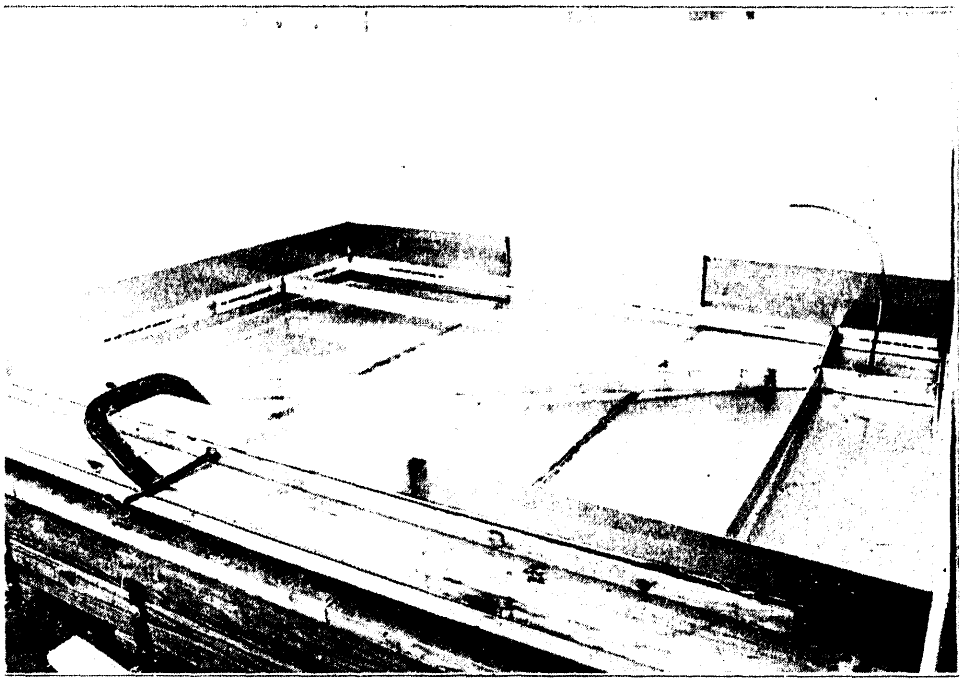


Photo 5 : Detail of tank pit floor & sump construction .

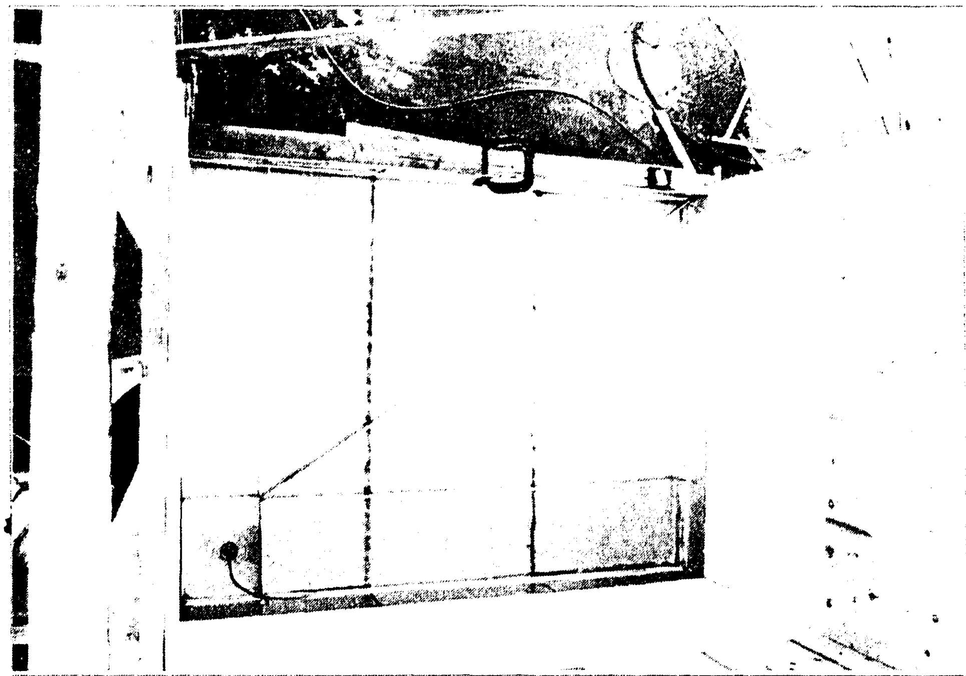


Photo 6 : Overhead view of floor slopes..

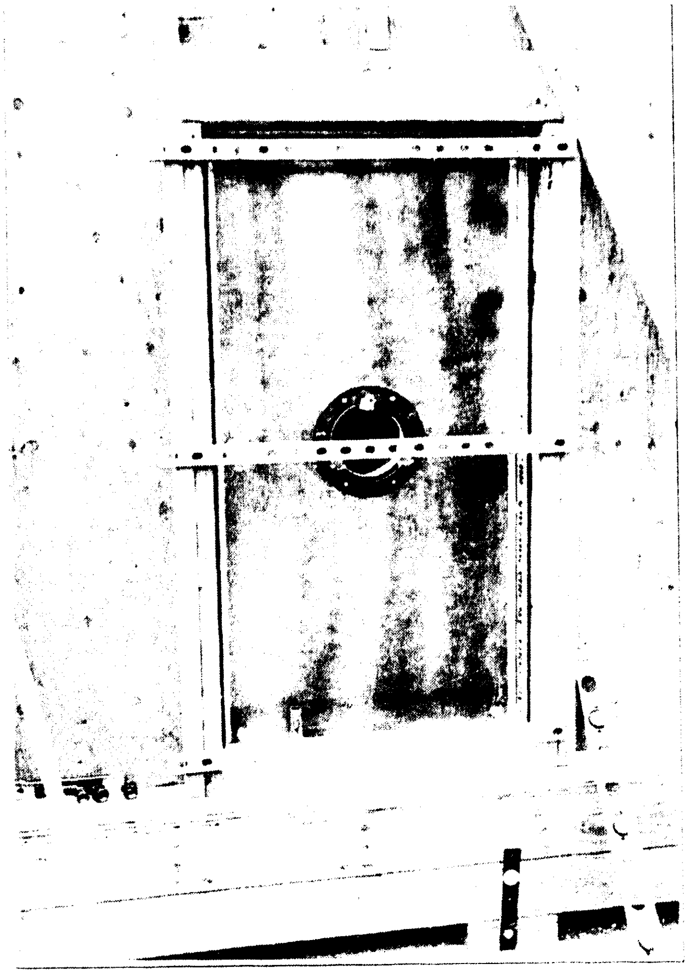


Photo 7 : Detail of sealed enclosure door and porthole

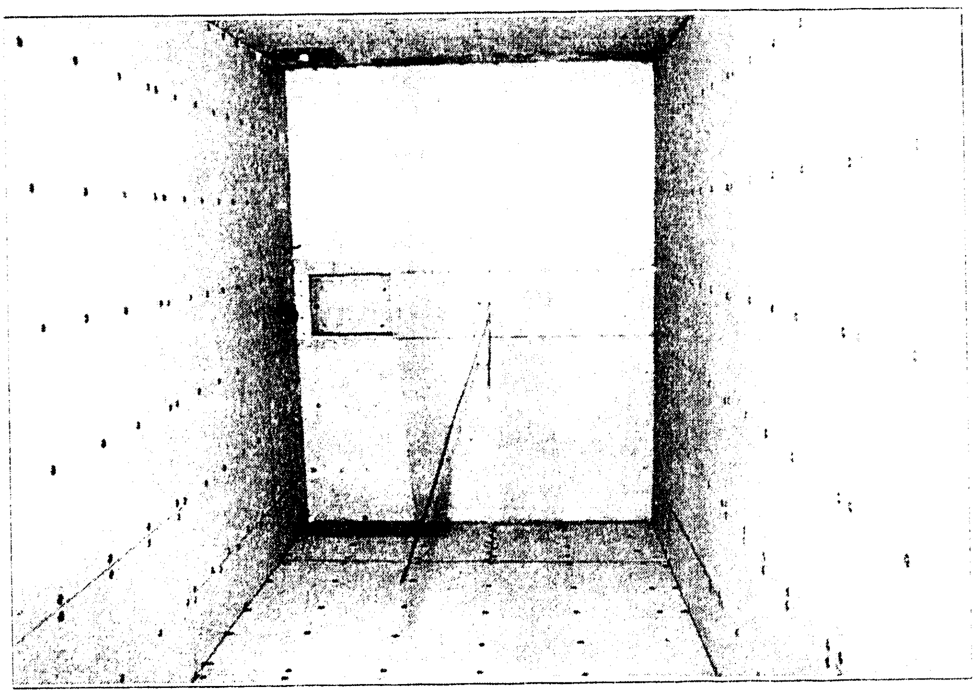


Photo 8: Interior view of Tank Pit ceiling.

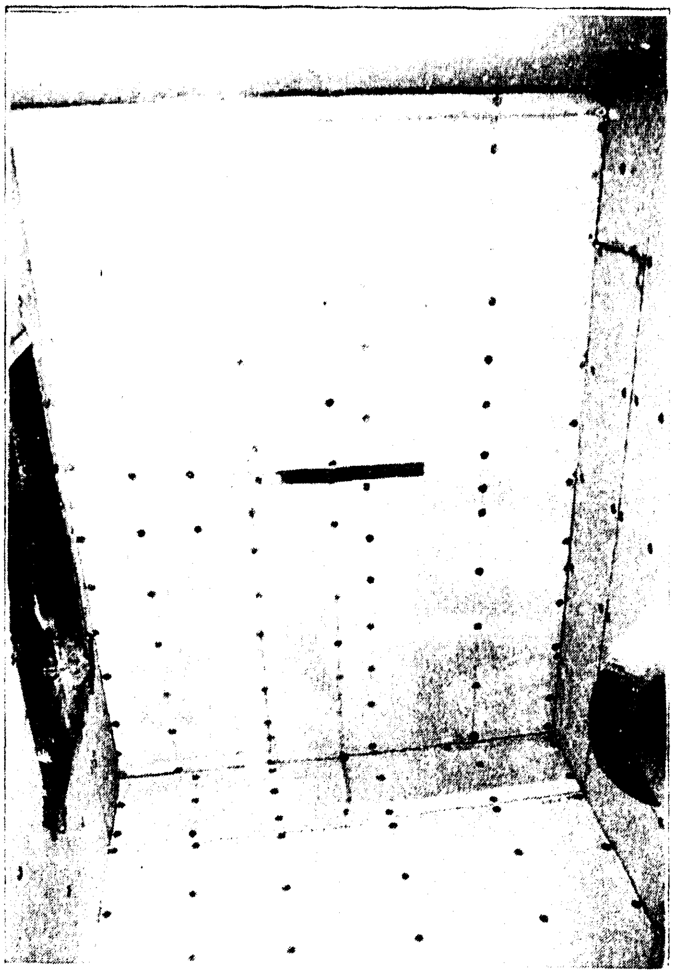


Photo 9 : Interior view of cubicle cell ceiling

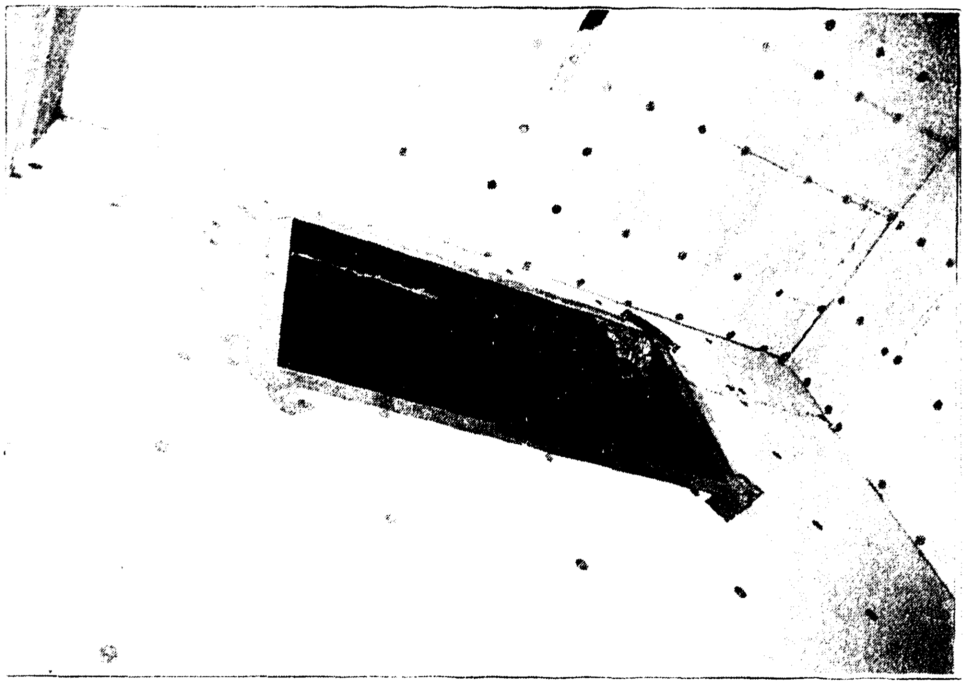


Photo 10 : Close up of 2' x 4' opening between cells.

Photo 11 : Detail of COG exhaust header

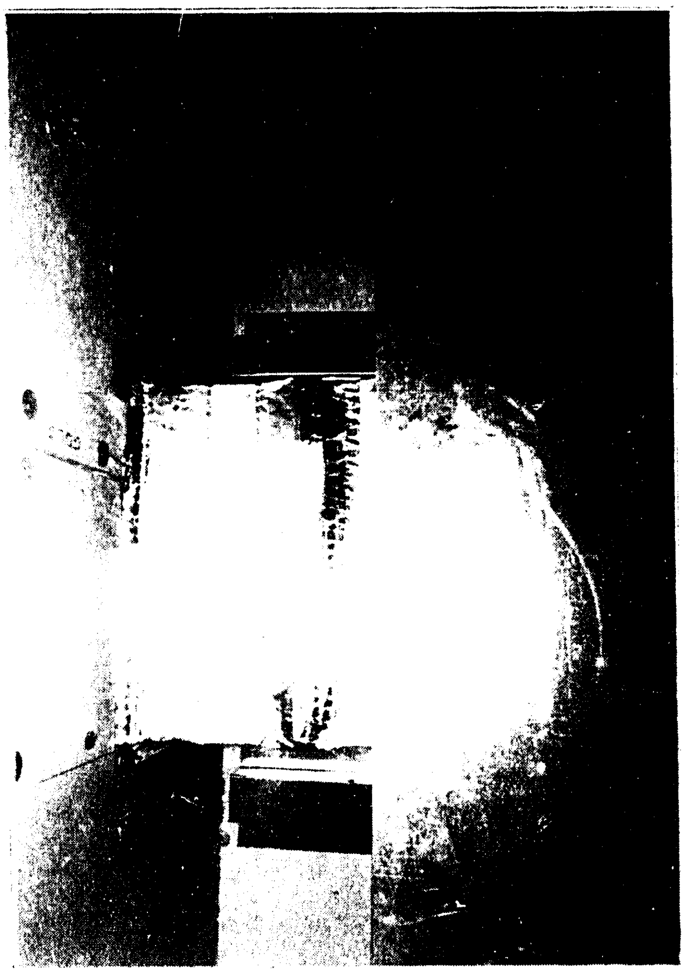


Photo 12 : Detail of COG duct out of cell

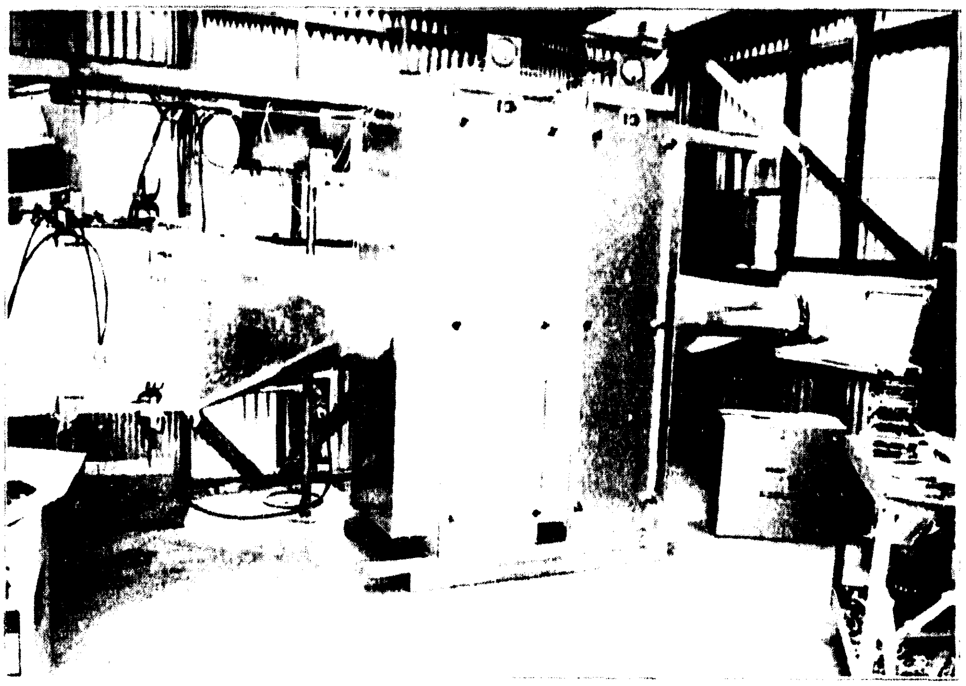


Photo 13 : Pre- filter and HEPA filter housing

Photo 14 : Close up of pre-filters and HEPA filters

Photo 15 : Variable speed blower

Photo 16 : Remote filling of kerosene

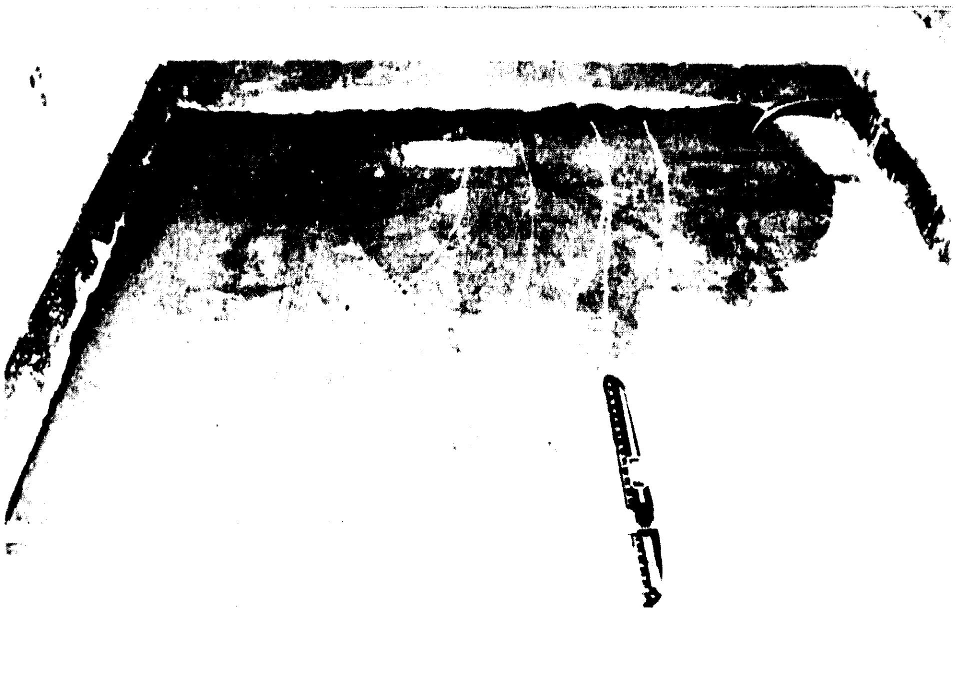


Photo 17 : Size of 40 liter kerosene spill (pre-test).

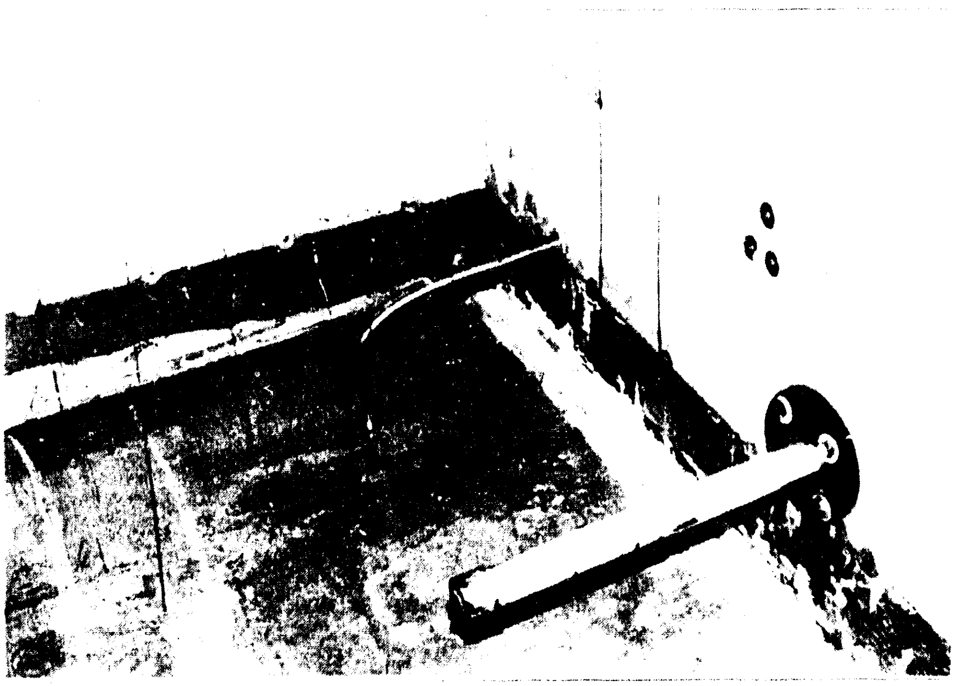


Photo 18 : Close-up of fill tube (bent) and fuel ignition port (light tube)

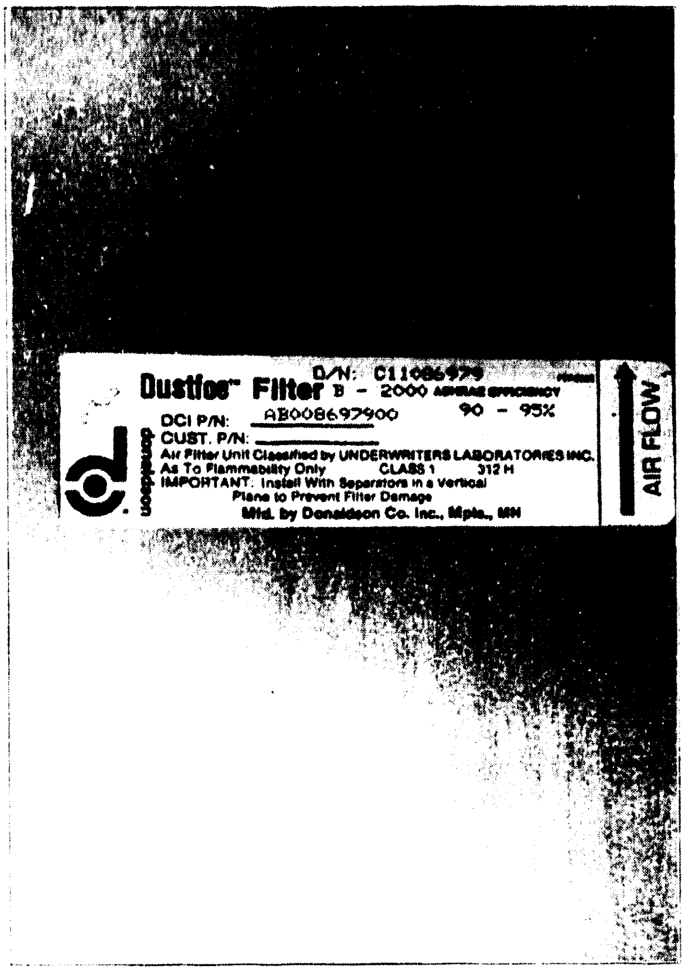


Photo 19 : Specification for
pre-filters

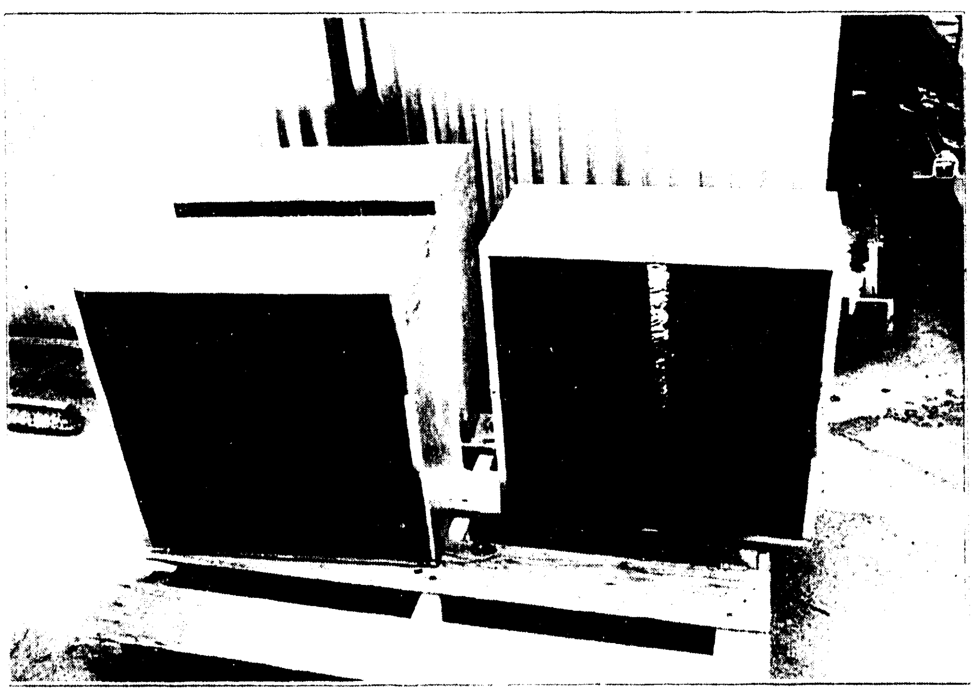


Photo 20 : Pre-filters removed after test O.R.N.L.
4.0

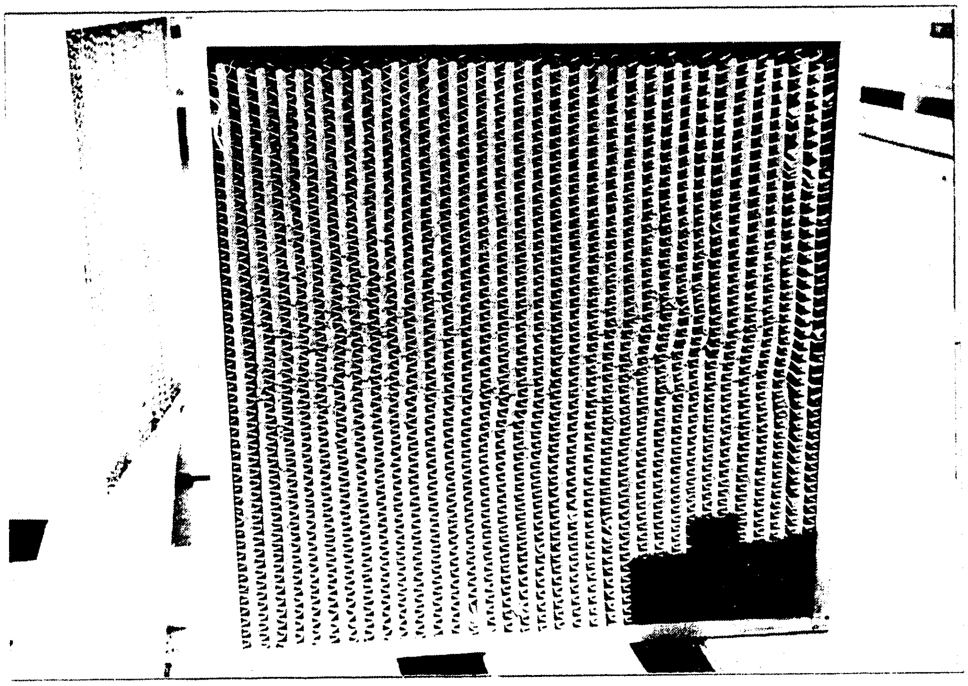


Photo 21: Close-up of used prefilter.

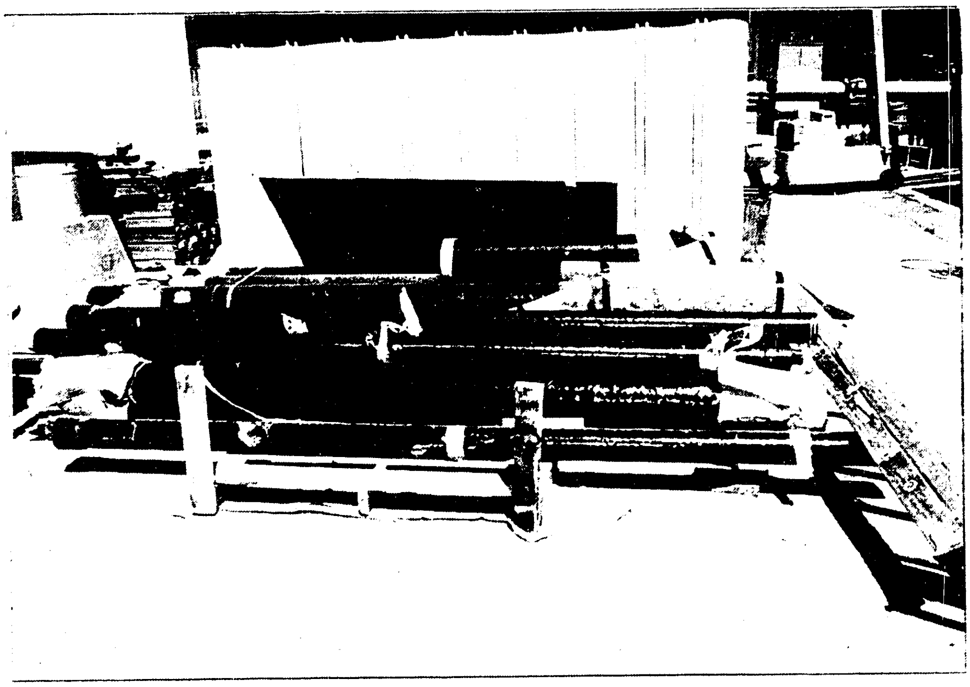


Photo 22 : FRP VOG duct before installation.

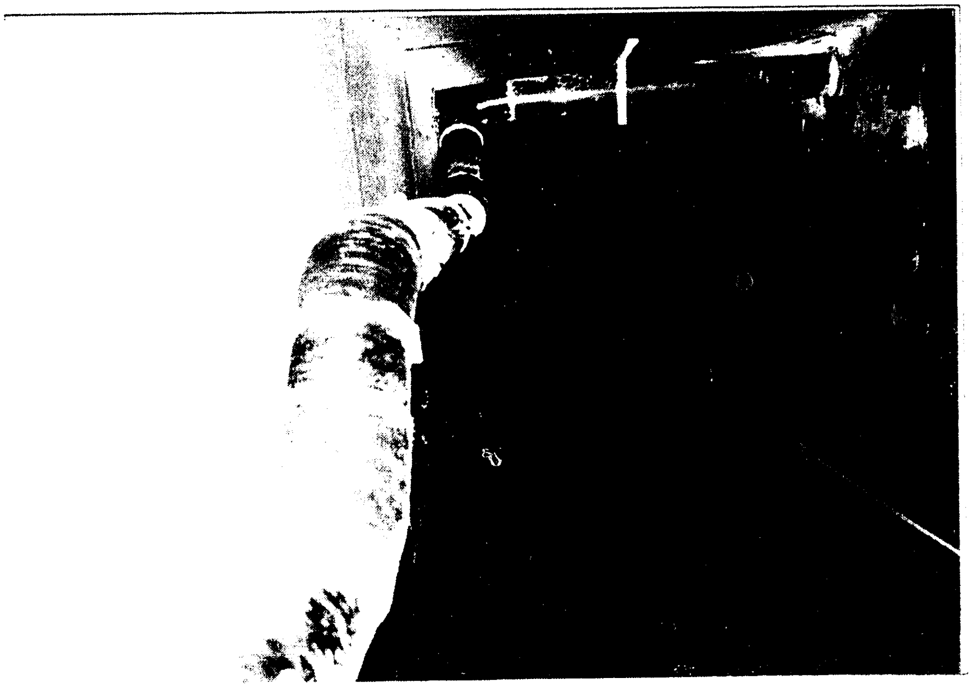


Photo 23: FRP VOG Duct installed ORNL Test 4.0.

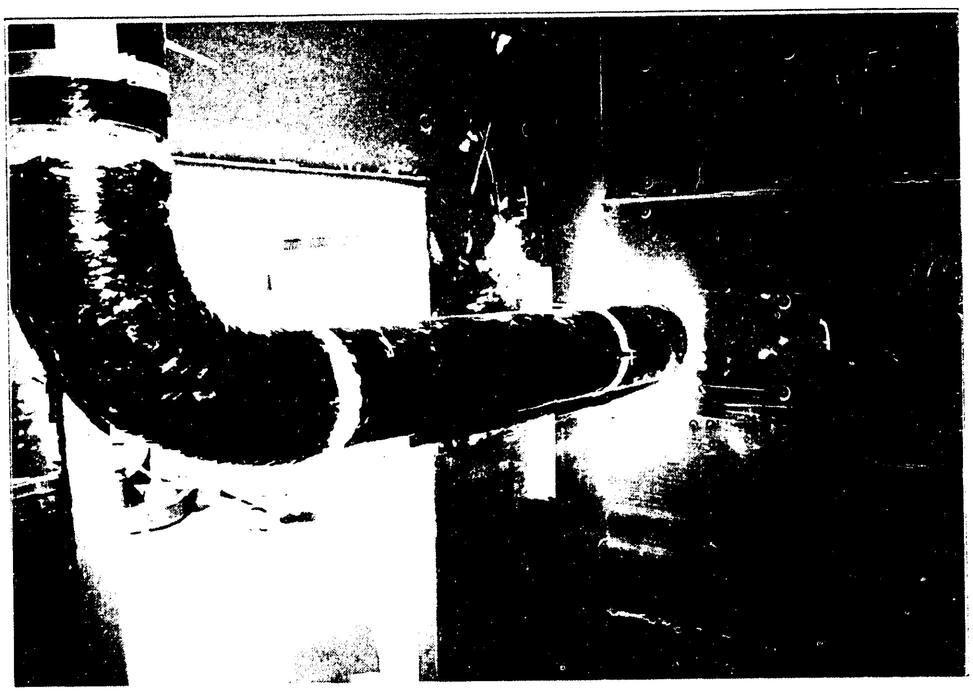


Photo 24 : FRP VOG Duct pre ORNL Test 4.0.

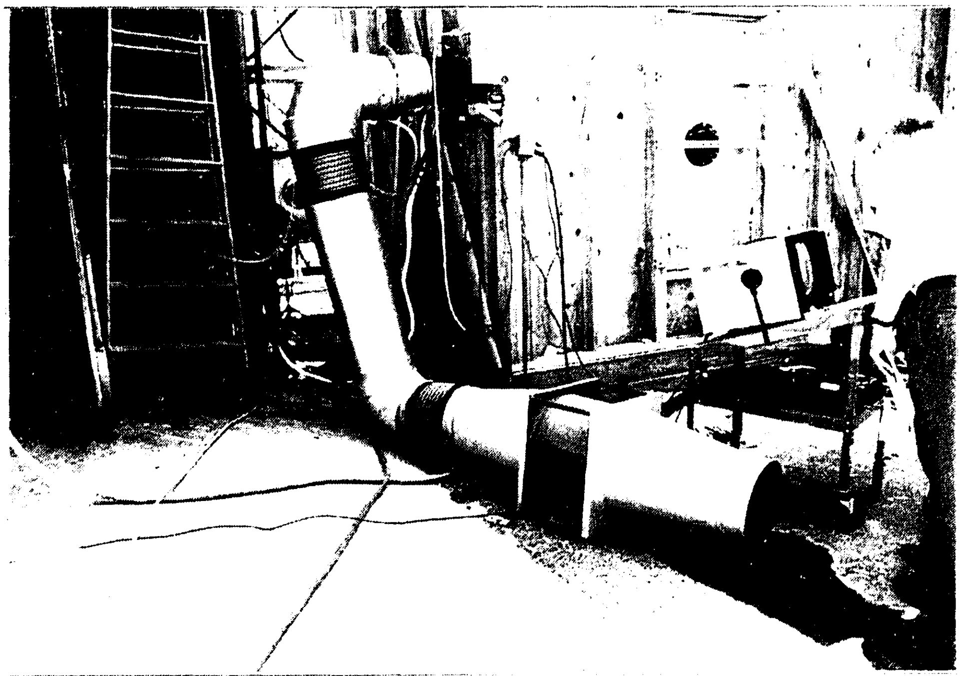


Photo 25 : Blower pulling air through FRP VOG duct.

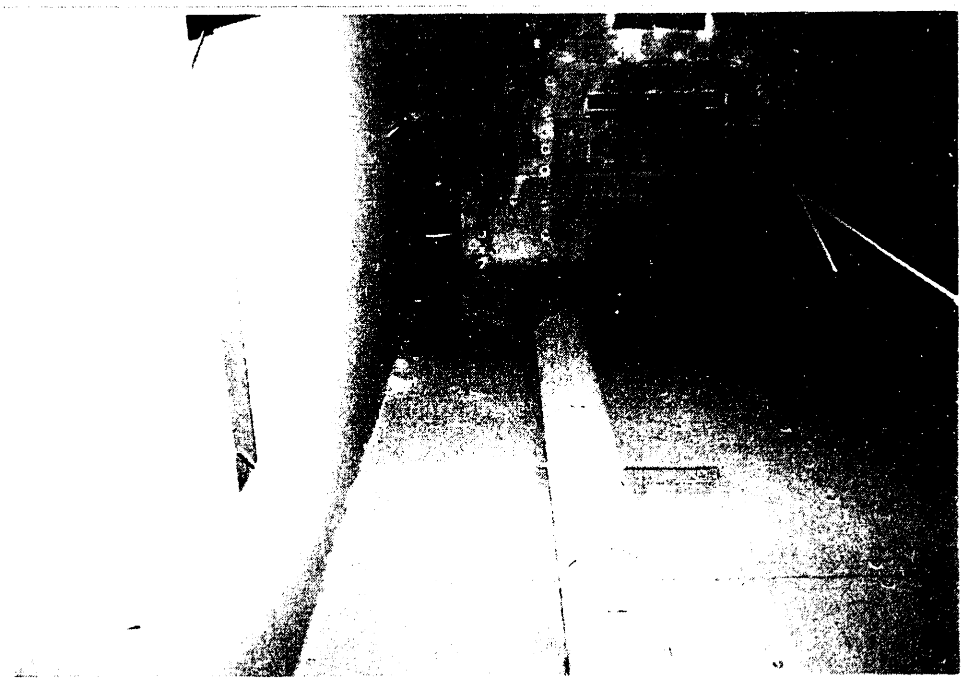


Photo 26 : FRP VOG duct covered with soot after ORNL Test 4.0.

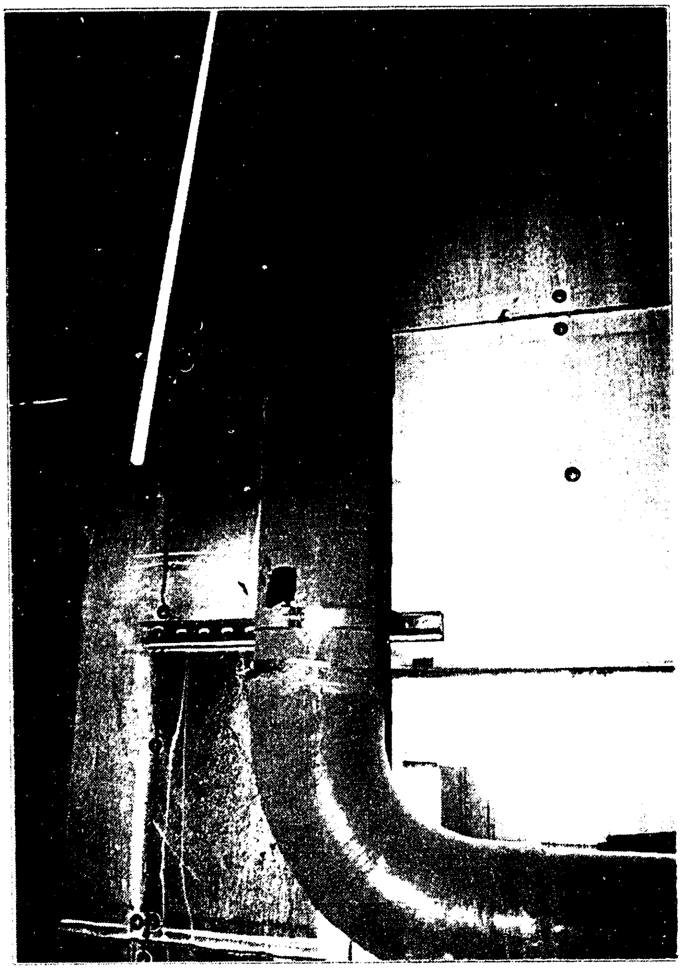


Photo 27 : FRP VOG duct after
ORNL Test 4.0.

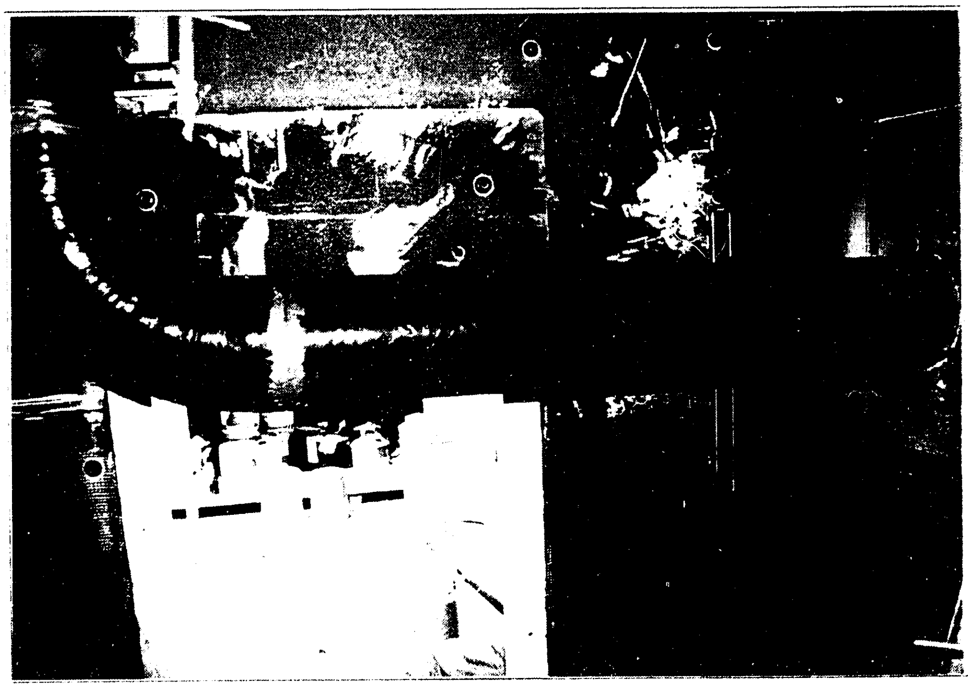


Photo 28 : FRP VOG duct closest to fire after
ORNL Test 4.0.

Photo 29 : Soot wiped off duct showing no thermal effect

Photo 30 : Soot wiped off duct showing no thermal effect

Photo 31 : Close up of tank pit sprinkler head

Photo 32 : Sprinkler spray pattern

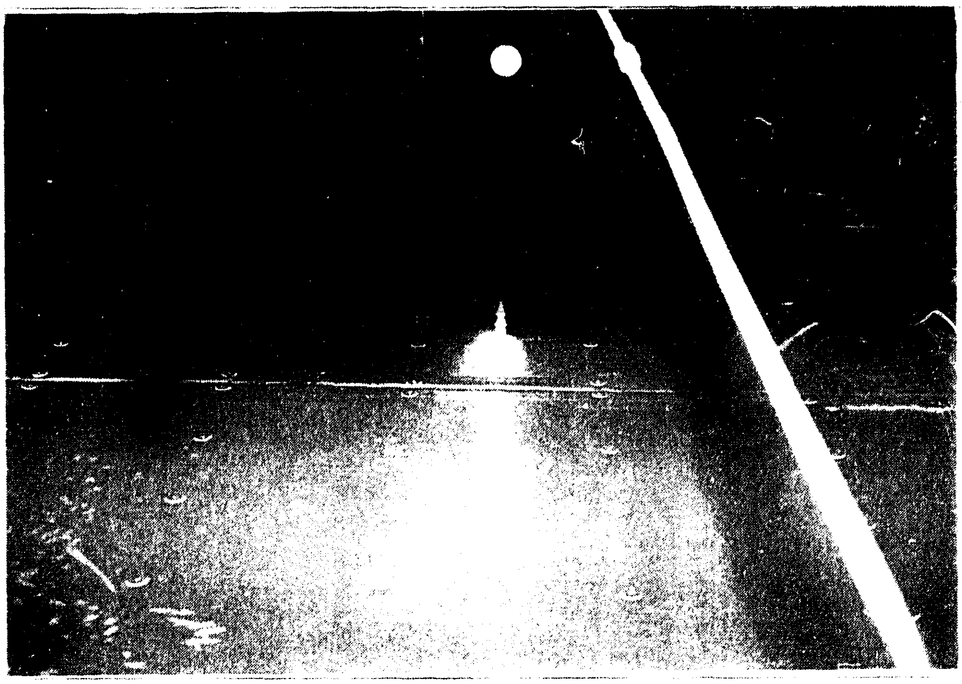


Photo 33 : Sprinkler installed on tank pit wall

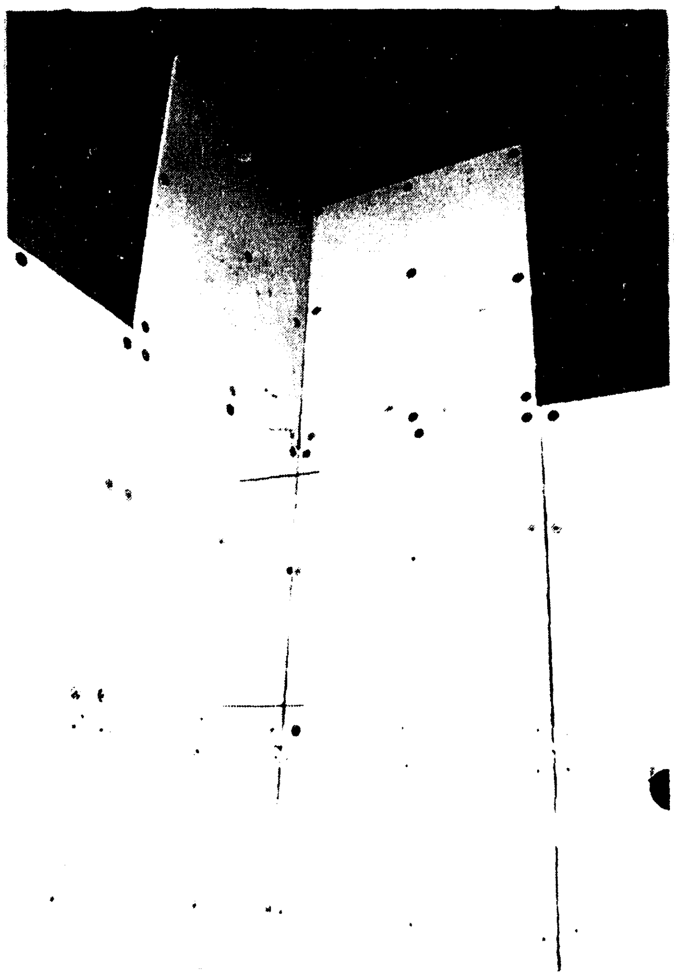
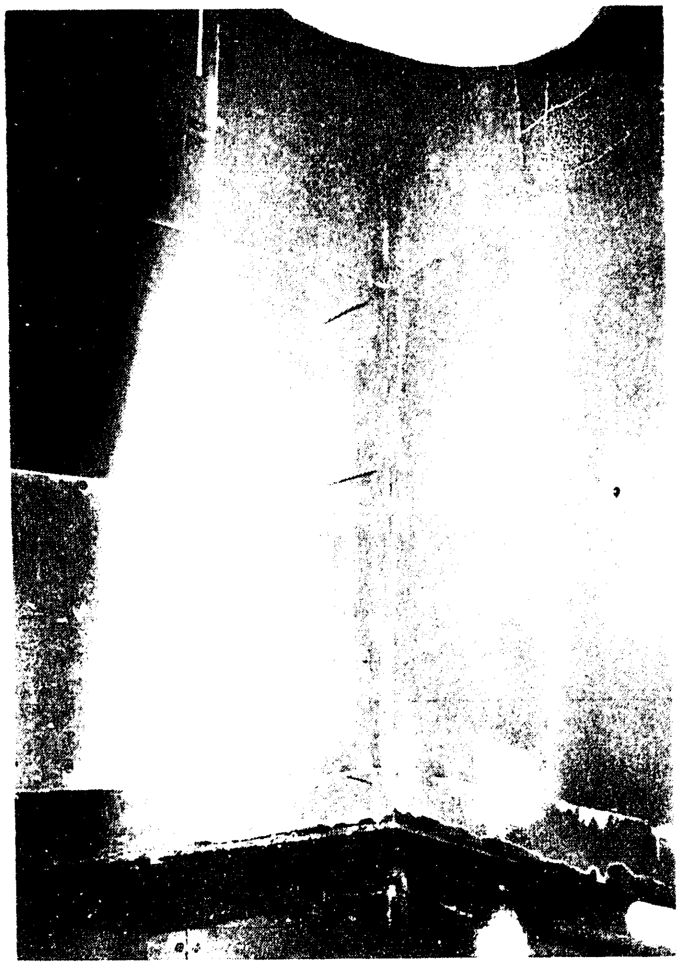


Photo 34 : Epoxy coated panel test set-up



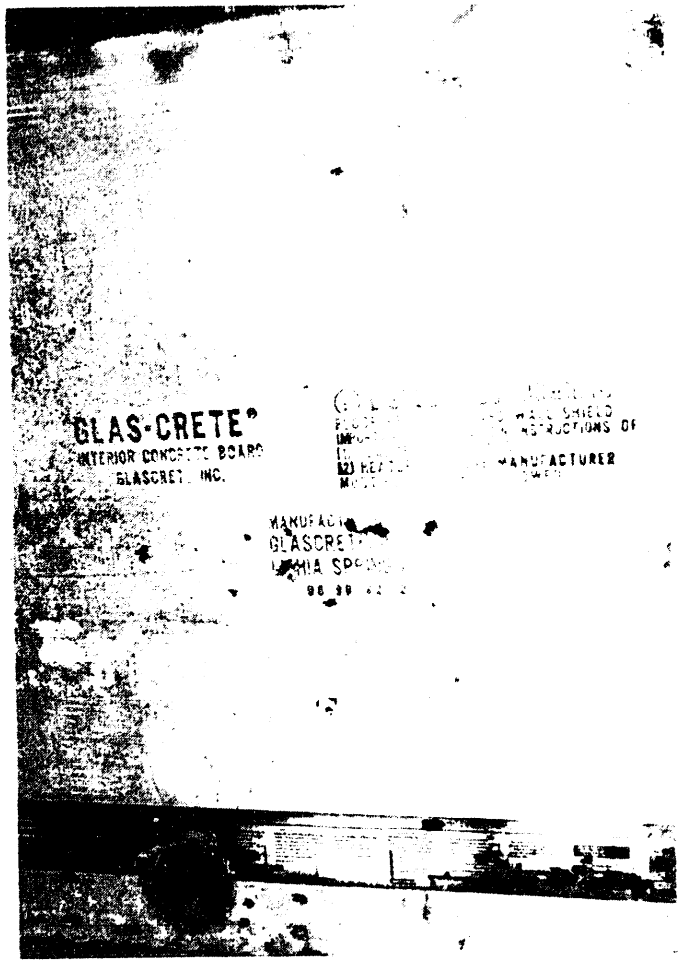

"GLAS-CRETE"
INTERIOR CONCRETE BOARD
GLASCRETE, INC.

Photo 37 : Condition of Gypsum board behind epoxy coated panels [post test]

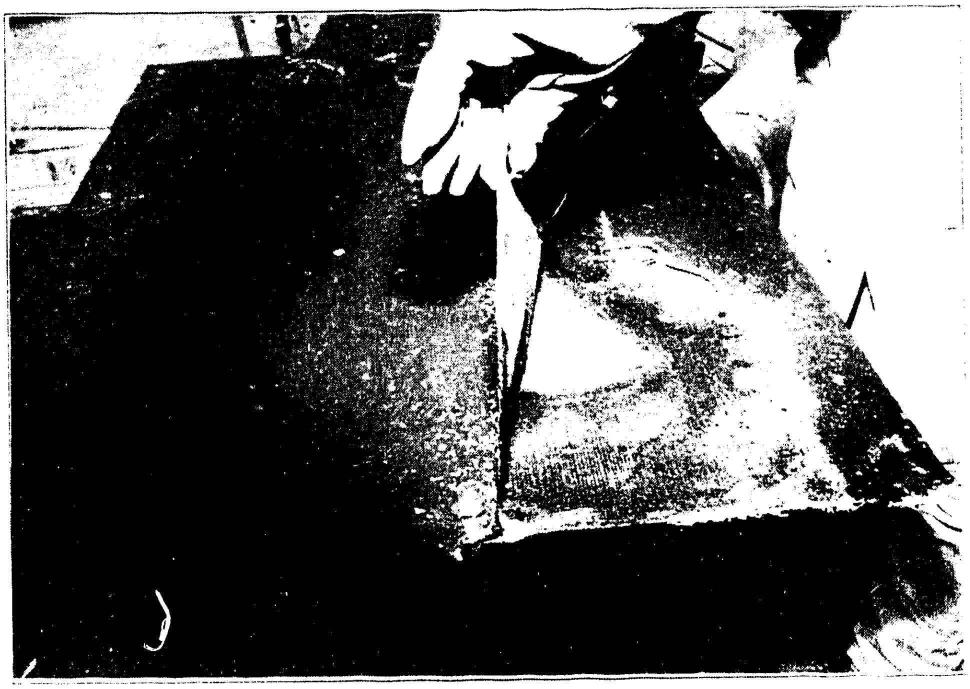


Photo 38 : Post- test close-up of epoxy coated panel

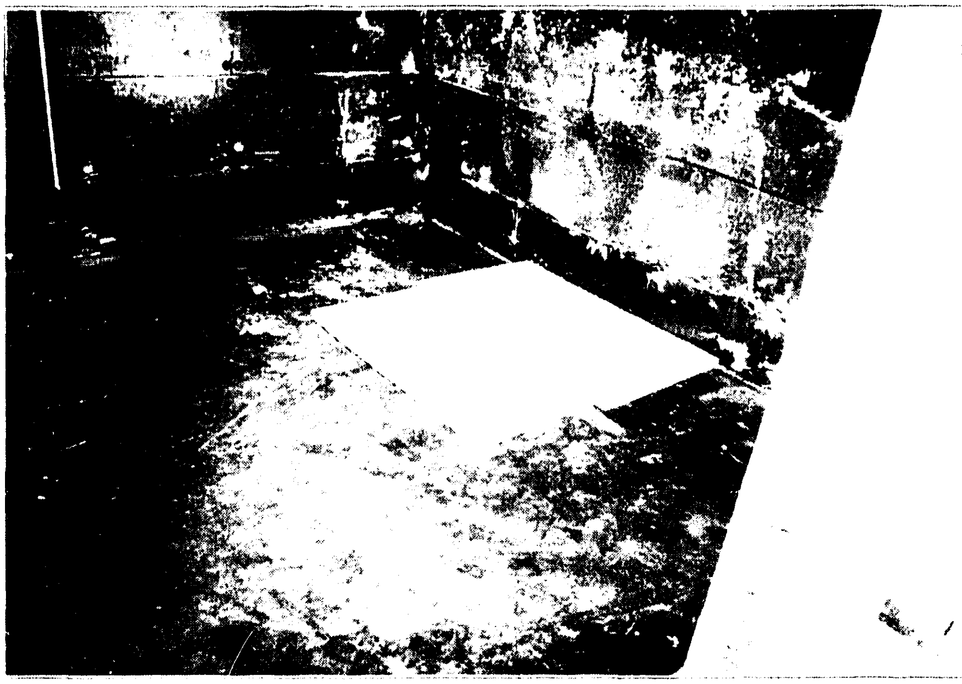


Photo 39 : Kerosene spill set-up for cubicle test

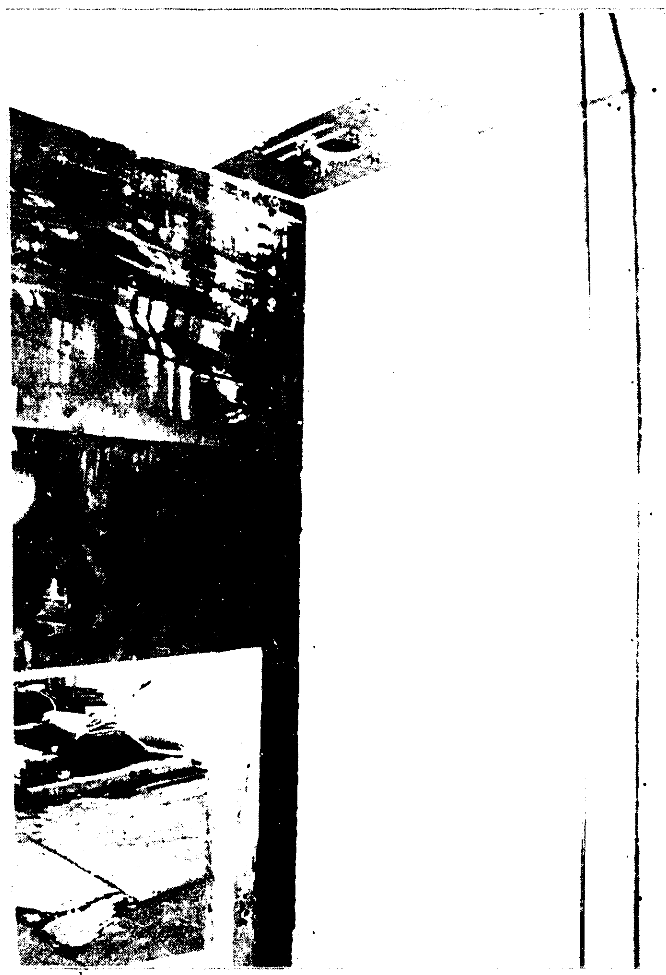


Photo 40 : Cubicle wall & ceiling set-up

Photo 41 : Close-up FRP elbow out of cubicle

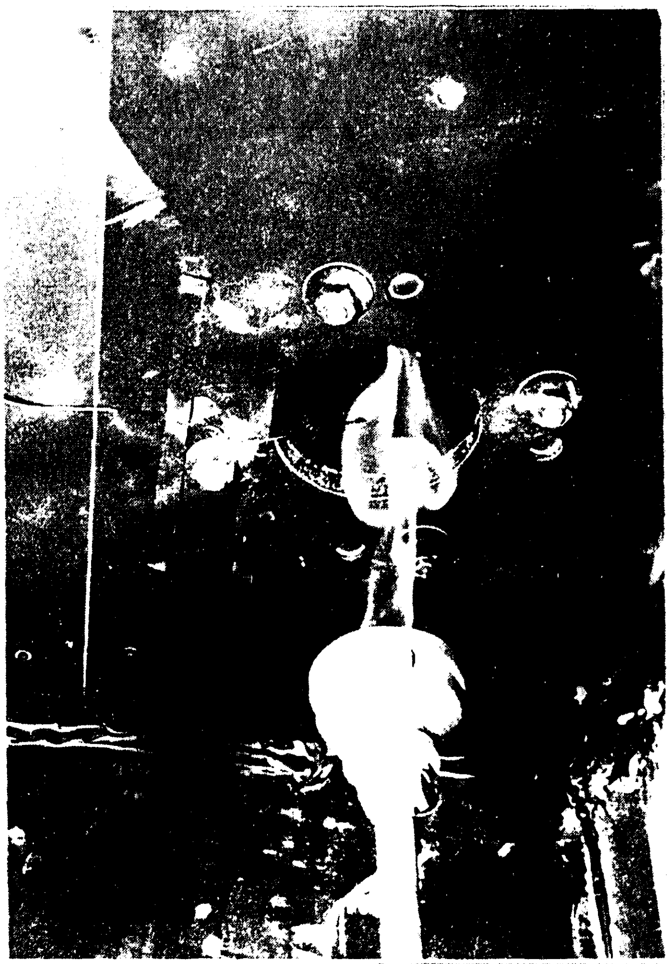


Photo 42 : Gas burner test directly into FRP elbow

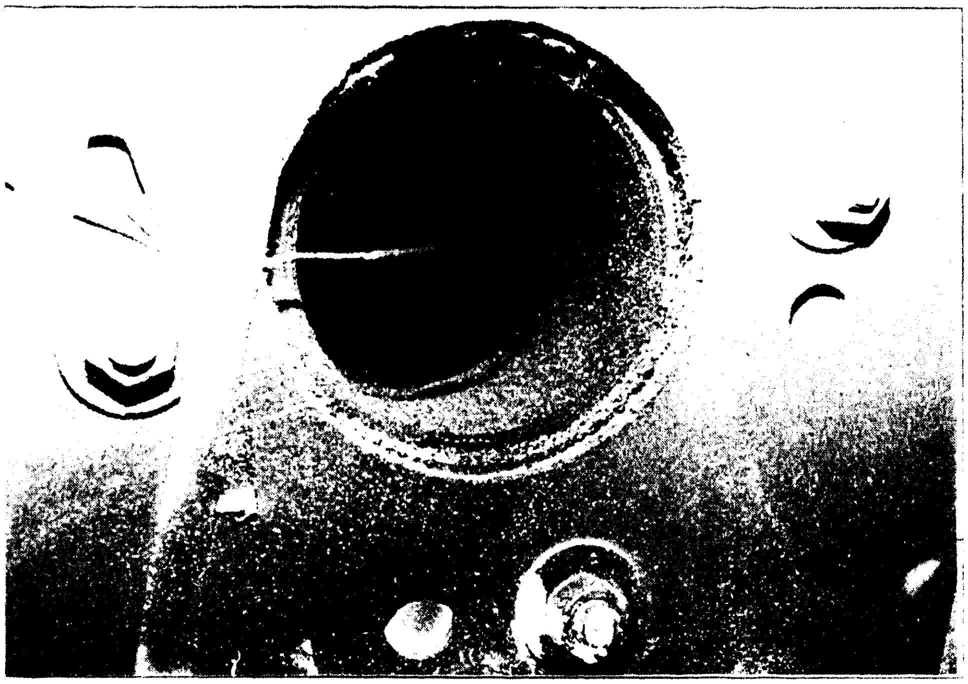


Photo 43 : Results of FRP elbow tests

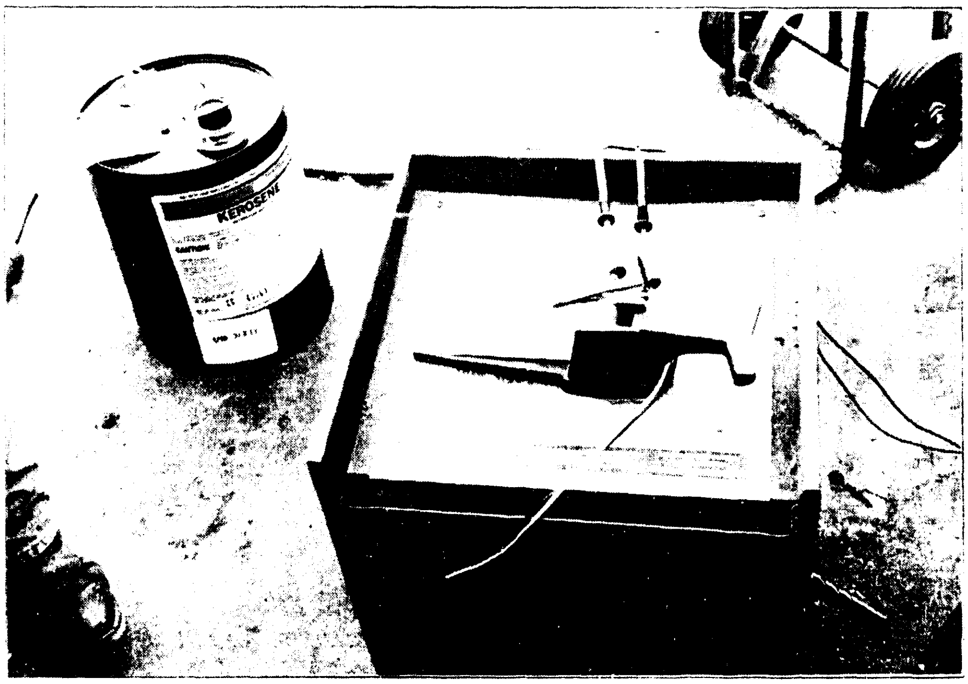


Photo 44 : Welder power supply for spark tests

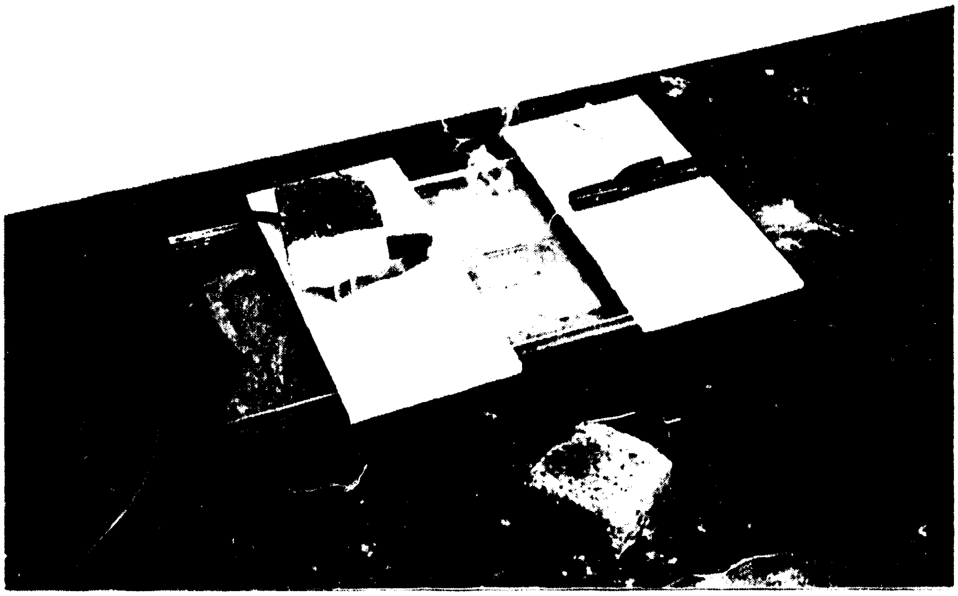


Photo 45 : Spark ignition tests

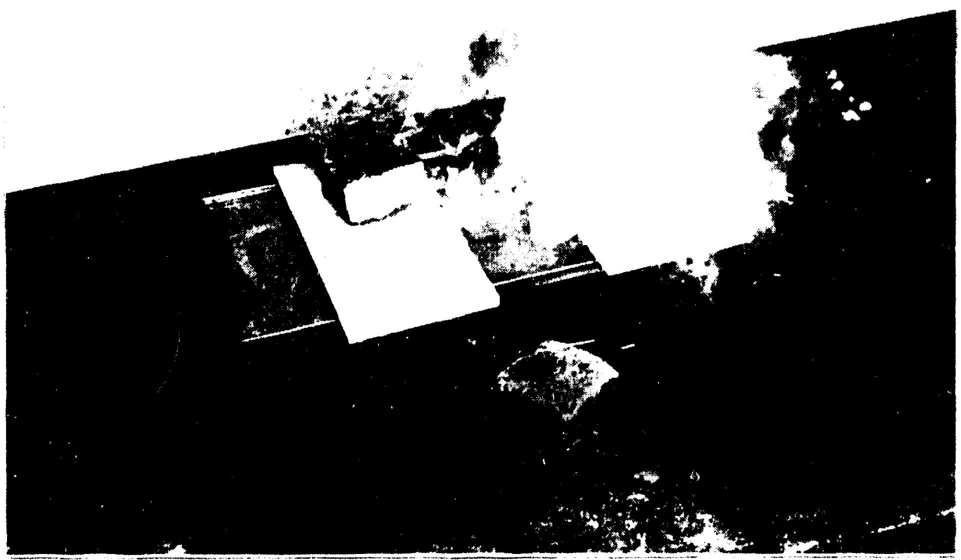


Photo 46 : Spark ignition tests

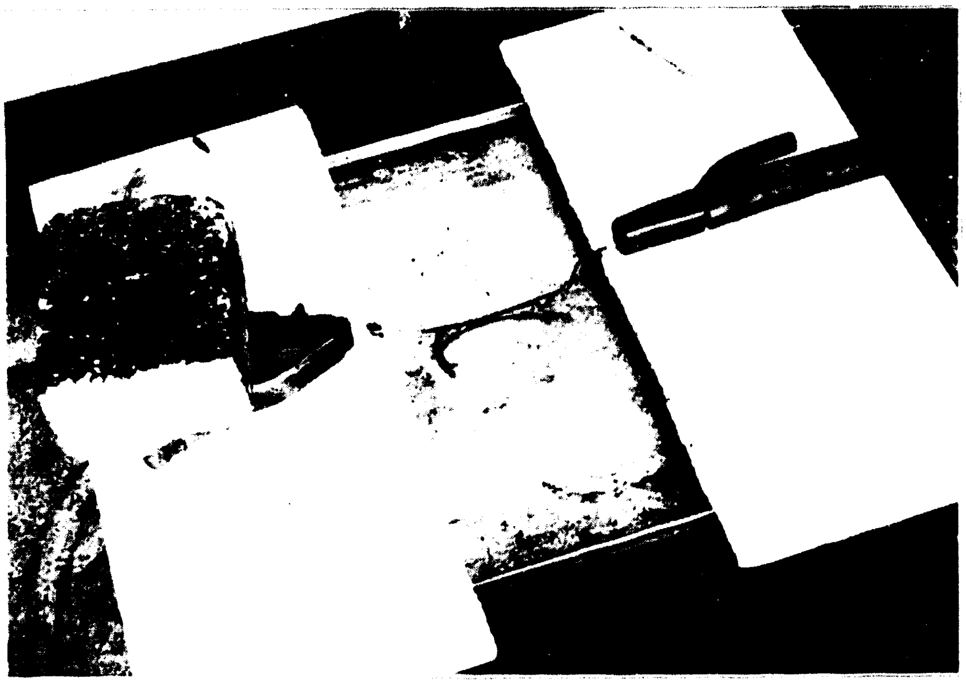
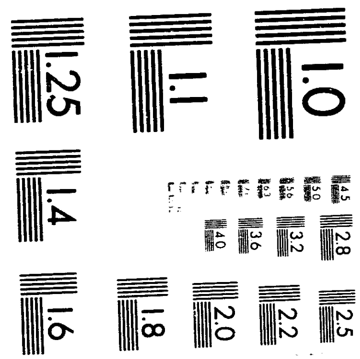


Photo 47 : Results of spark ignition tests


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

2 of 3

DATA PLOTS

Date: 17 Jun 19 Time: 16:49:32

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL1.0	CH-0	NE TC RAKE 6" UP	Degrees Celsius	500
◆ ORNL1.0	CH-1	NE TC RAKE 2' UP	Degrees Celsius	500
× ORNL1.0	CH-2	NE TC RAKE 4' UP	Degrees Celsius	500
● ORNL1.0	CH-3	NE TC RAKE 6' UP	Degrees Celsius	500
■ ORNL1.0	CH-4	NE TC RAKE 8' UP	Degrees Celsius	500
◇ ORNL1.0	CH-5	NE TC RAKE 10' UP	Degrees Celsius	500

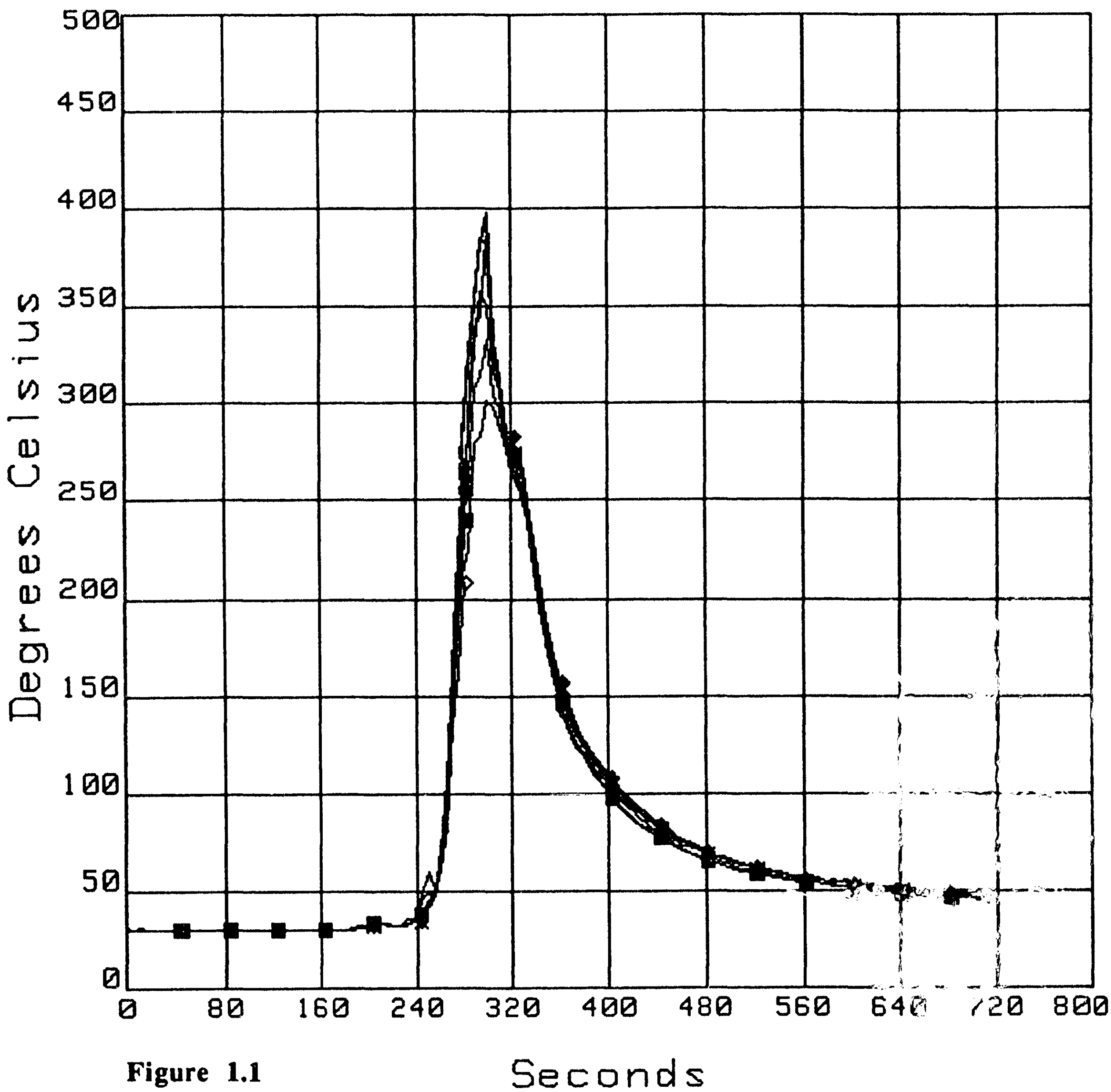
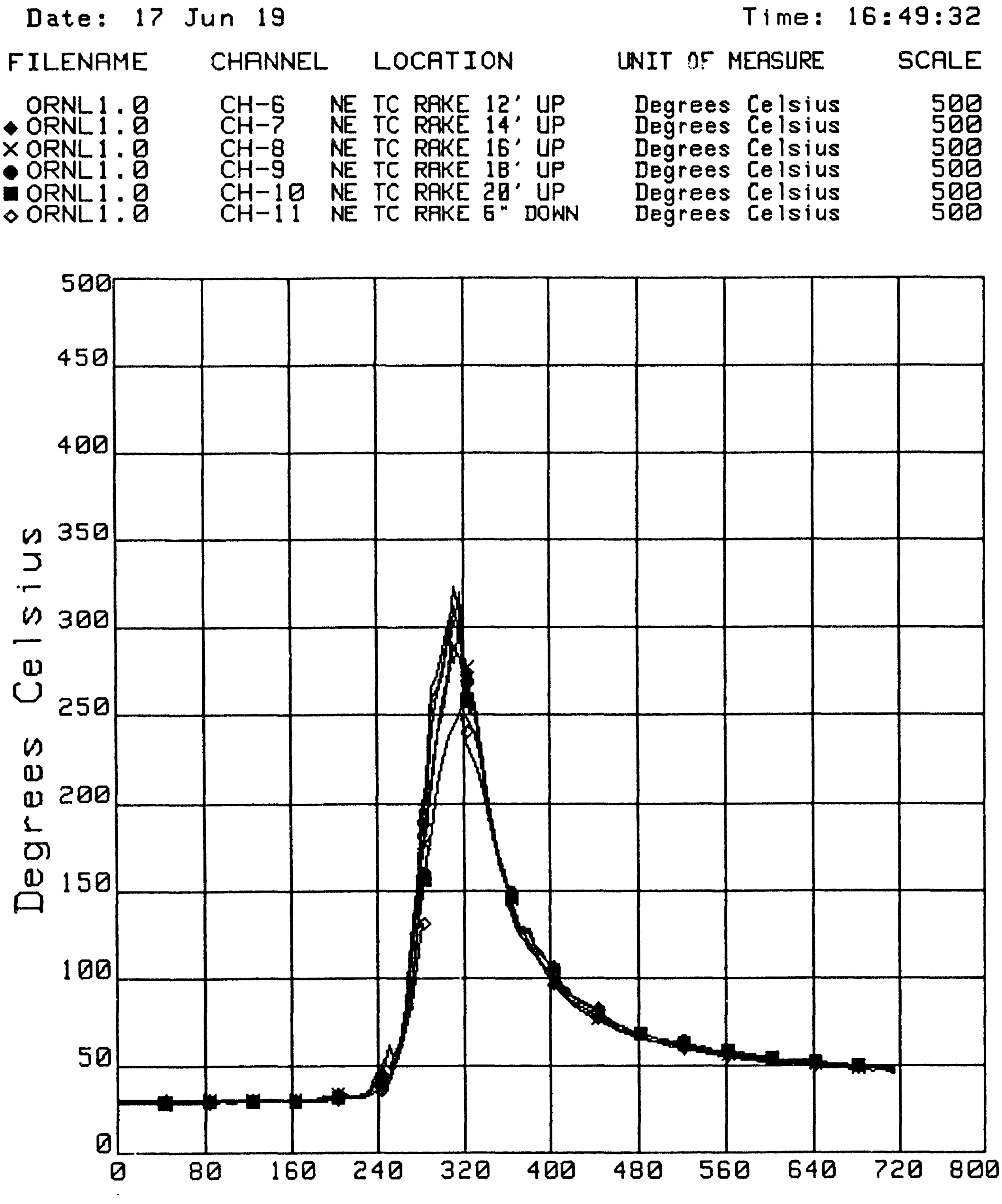


Figure 1.1



Date: 17 Jun 19
Time: 16:49:32
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL1.0 CH-6 NE TC RAKE 12' UP Degrees Celsius 500
◆ ORNL1.0 CH-7 NE TC RAKE 14' UP Degrees Celsius 500
× ORNL1.0 CH-8 NE TC RAKE 16' UP Degrees Celsius 500
● ORNL1.0 CH-9 NE TC RAKE 18' UP Degrees Celsius 500
■ ORNL1.0 CH-10 NE TC RAKE 20' UP Degrees Celsius 500
◇ ORNL1.0 CH-11 NE TC RAKE 6" DOWN Degrees Celsius 500
Degrees Celsius
500
450
400
350
300
250
200
150
100
50
0
0
80
160
240
320
400
480
560
640
720
800
Seconds

Figure 1.2

Date: 17 Jun 19 Time: 16:49:32

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL1.0	CH-20	So TC RAKE 6" UP	Degrees Celsius	1200
◆ ORNL1.0	CH-21	So TC RAKE 2' UP	Degrees Celsius	1200
× ORNL1.0	CH-22	So TC RAKE 4' UP	Degrees Celsius	1200
● ORNL1.0	CH-23	So TC RAKE 6' UP	Degrees Celsius	1200

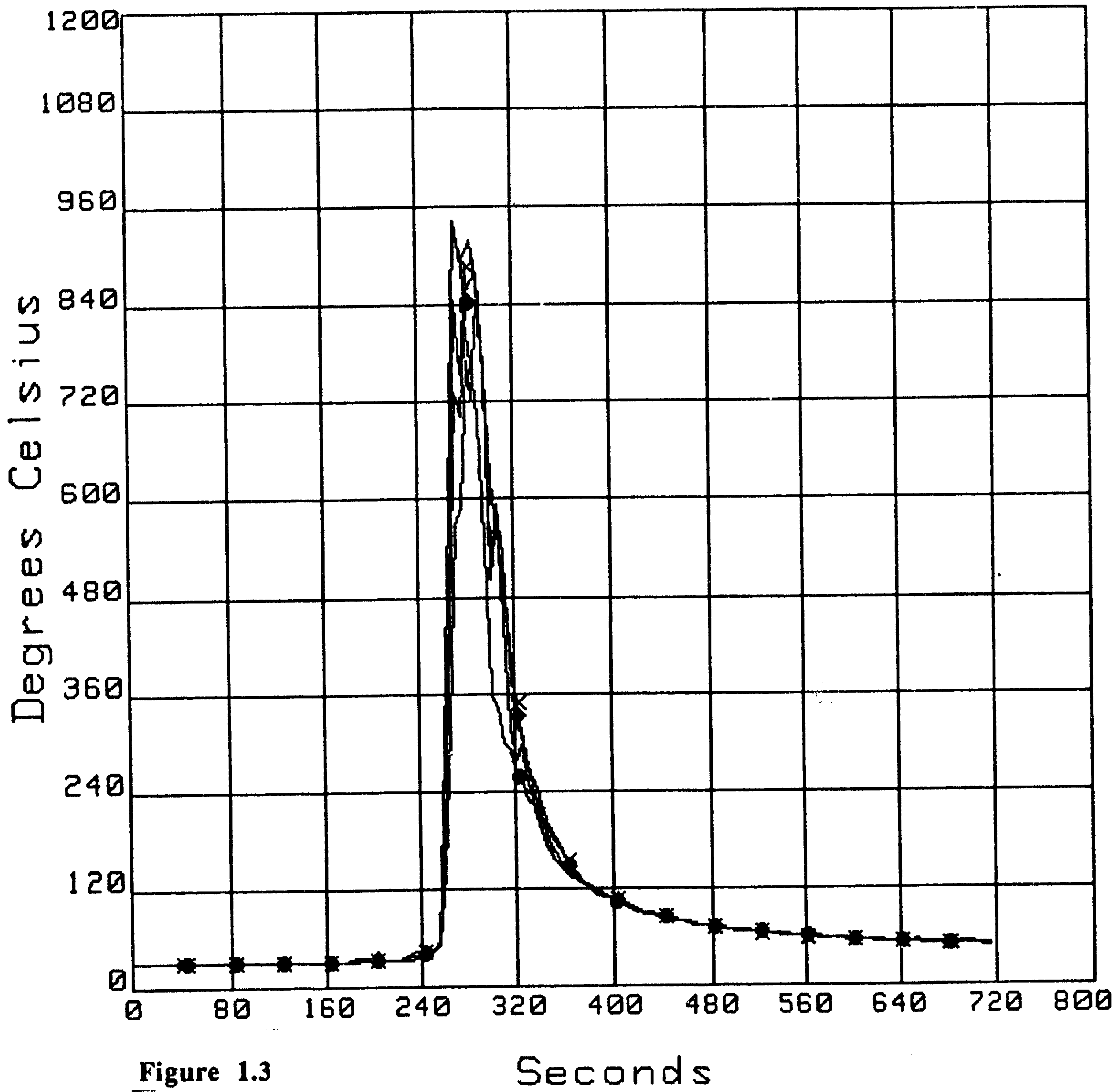


Figure 1.3

Date: 17 Jun 19 Time: 16:49:32

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL1.0	CH-27	TOP So WINDOW TC	Degrees Celsius	500
◆ ORNL1.0	CH-28	TOP No WINDOW TC	Degrees Celsius	500
× ORNL1.0	CH-29	BOTTOM So WINDOW TC	Degrees Celsius	500
● ORNL1.0	CH-30	BOTTOM No WINDOW TC	Degrees Celsius	500

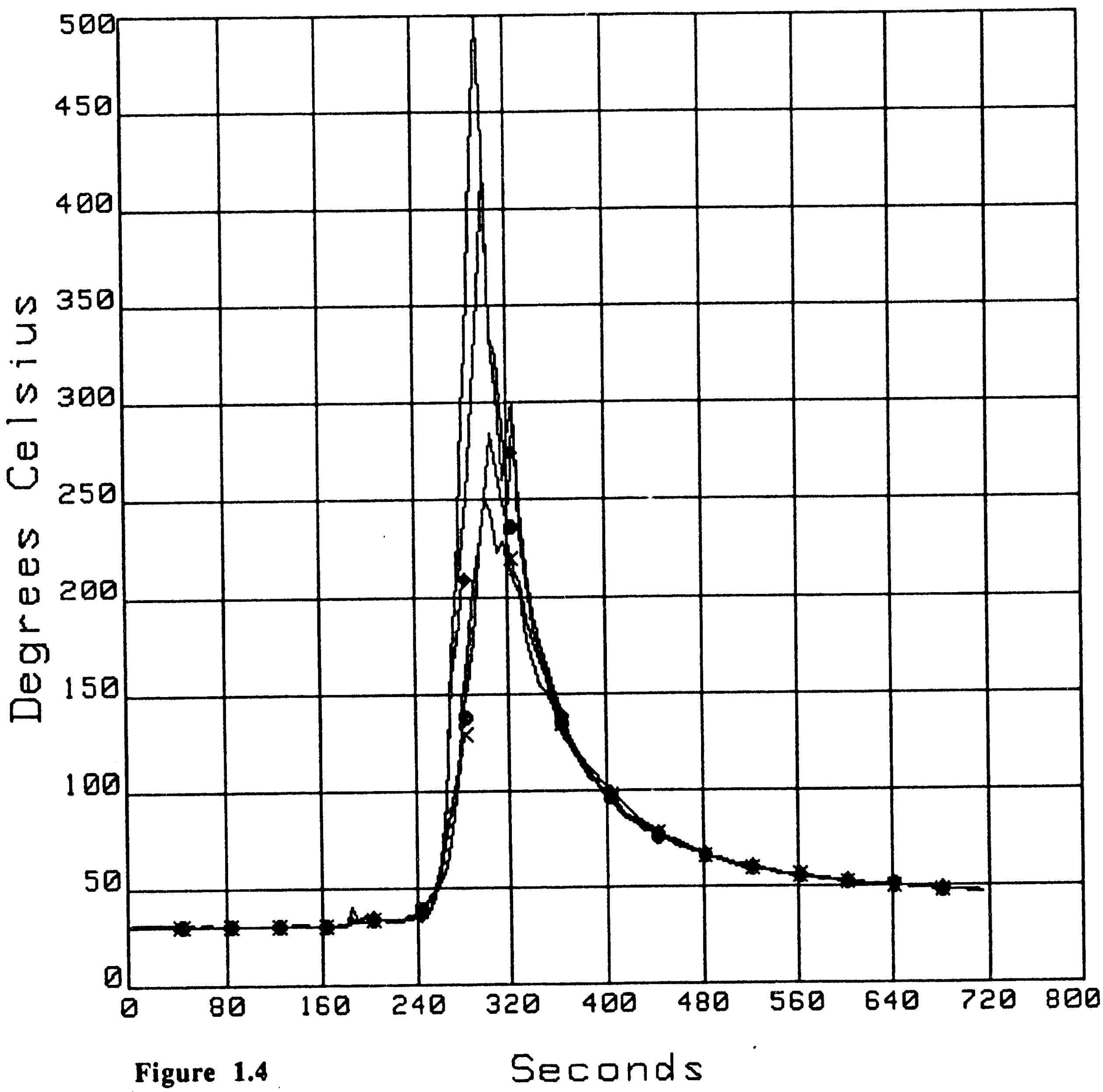


Figure 1.4

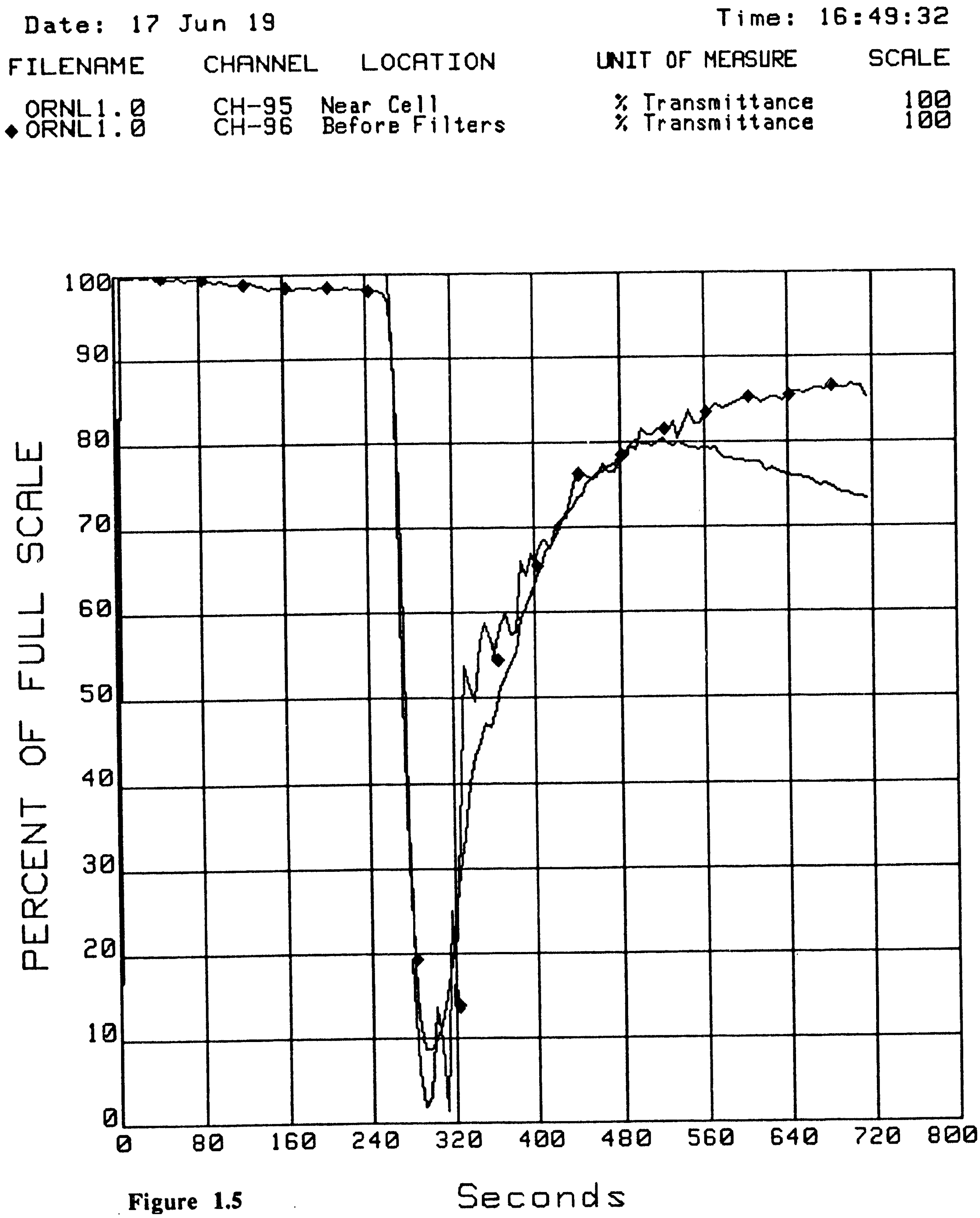

Date: 17 Jun 19
Time: 16:49:32
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL1.0 CH-95 Near Cell % Transmittance 100
◆ORNL1.0 CH-96 Before Filters % Transmittance 100
PERCENT OF FULL SCALE
100
90
80
70
60
50
40
30
20
10
0
0 80 160 240 320 400 480 560 640 720 800
Seconds

Figure 1.5

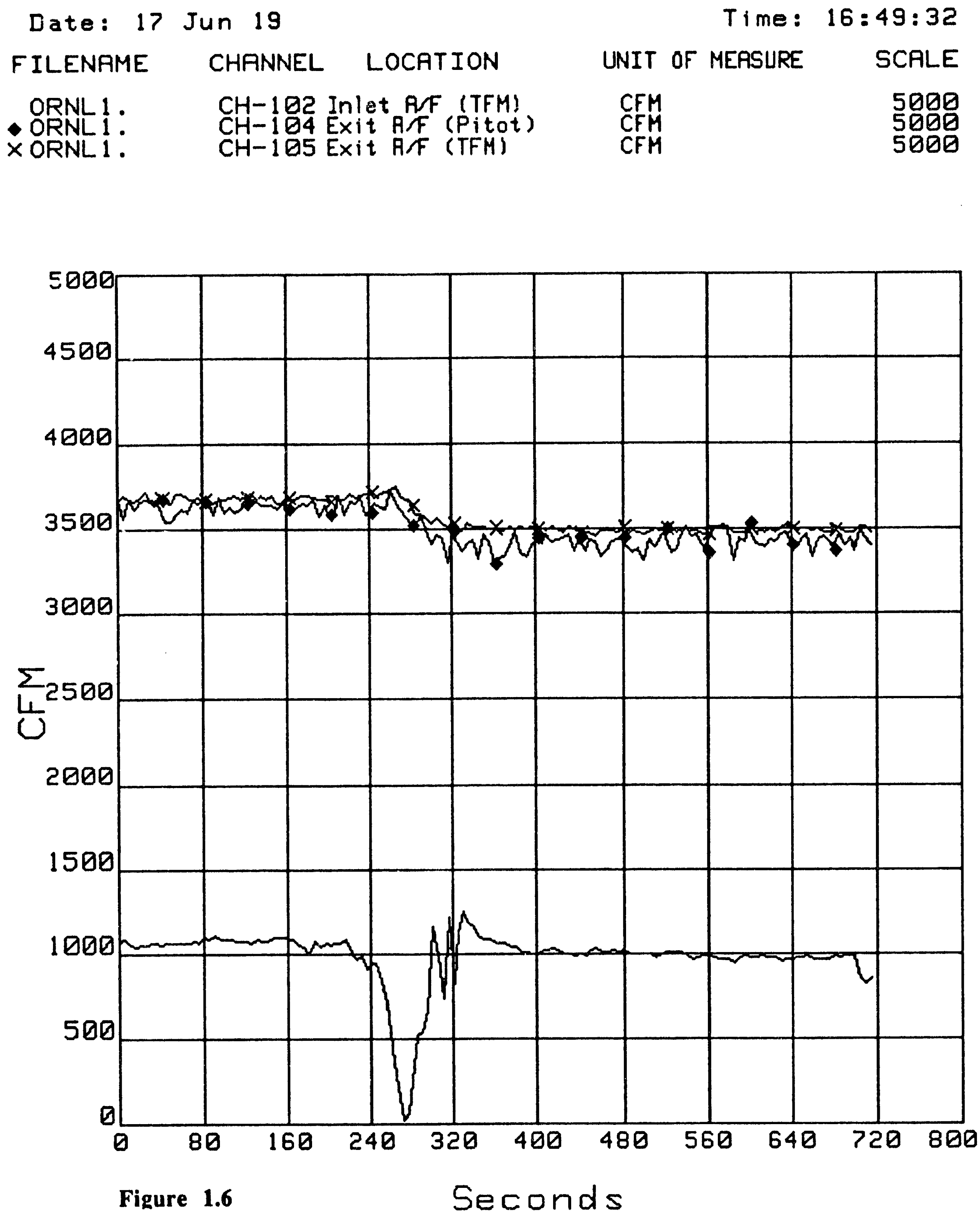

Date: 17 Jun 19
Time: 16:49:32
FILENAME
CHANNEL
LOCATION
UNIT OF MEASURE
SCALE
ORNL1. CH-102 Inlet A/F (TFM) CFM 5000
◆ ORNL1. CH-104 Exit A/F (Pitot) CFM 5000
× ORNL1. CH-105 Exit A/F (TFM) CFM 5000
CFM
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
80
160
240
320
400
480
560
640
720
800
Seconds

Figure 1.6

Date: 17 Jun 19 Time: 16:49:32

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL1.0	CH-109	Delta P HEPA	INCHES H20	5
◆ ORNL1.0	CH-110	Delta P PreFilter	INCHES H20	5

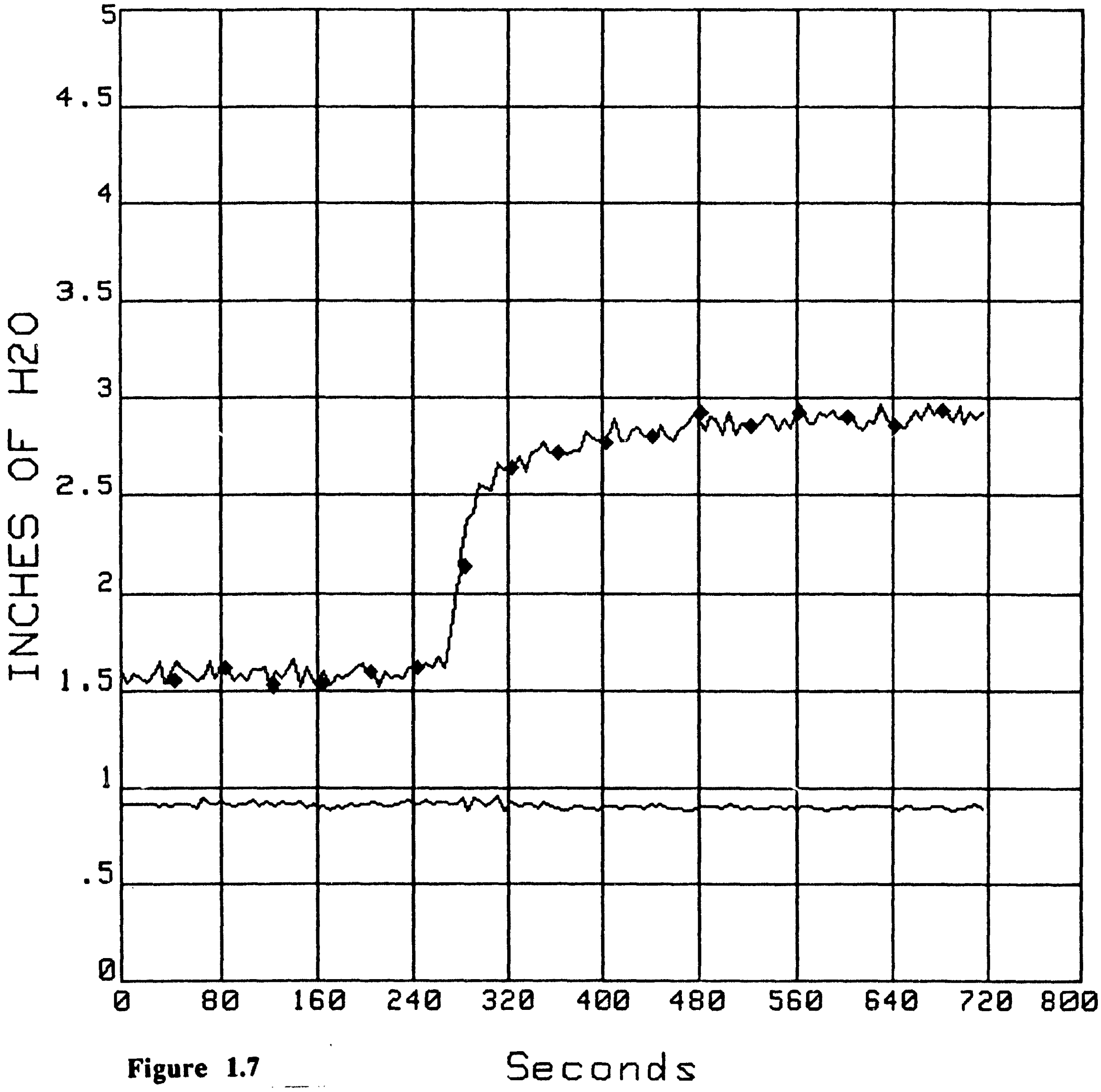


Figure 1.7

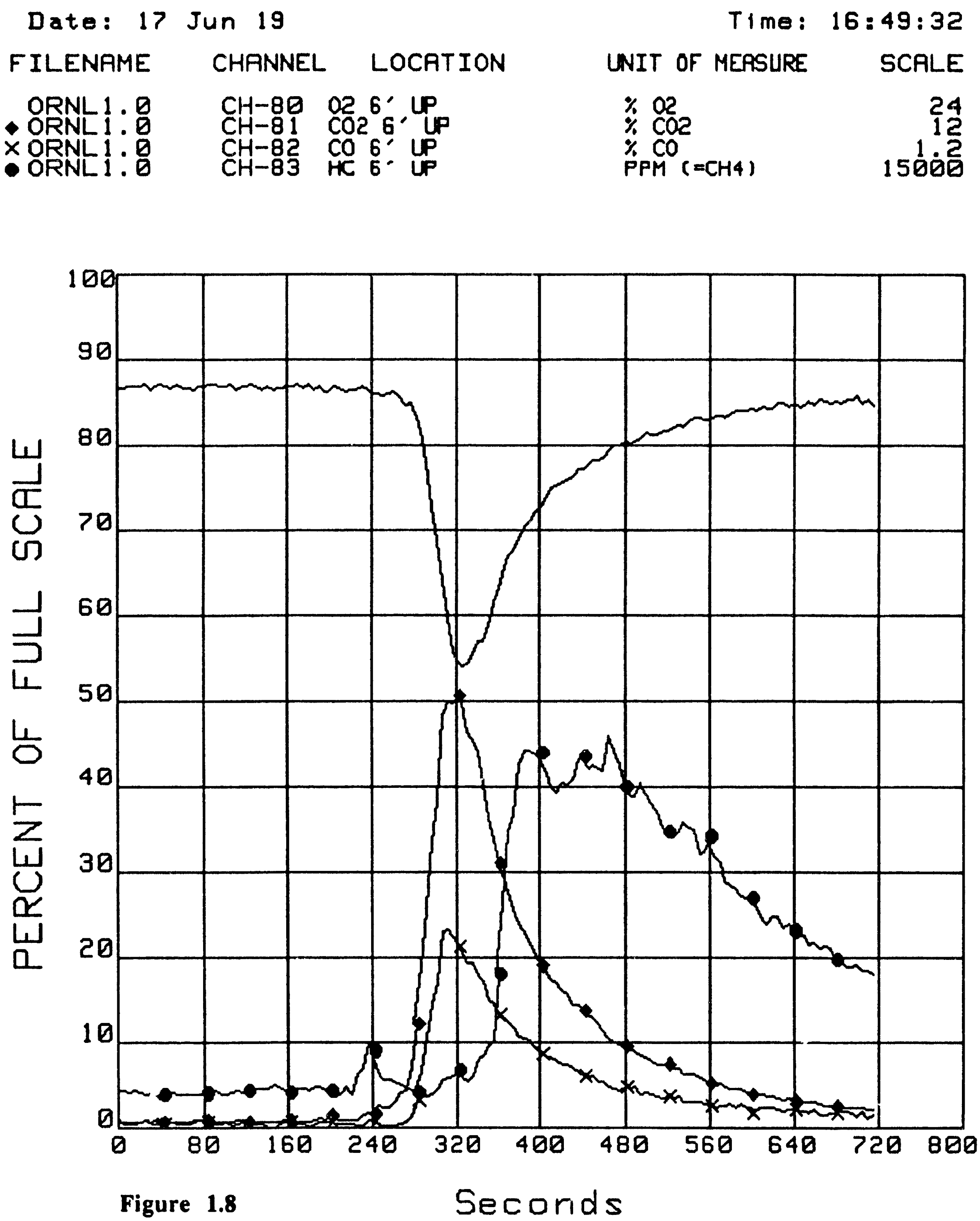
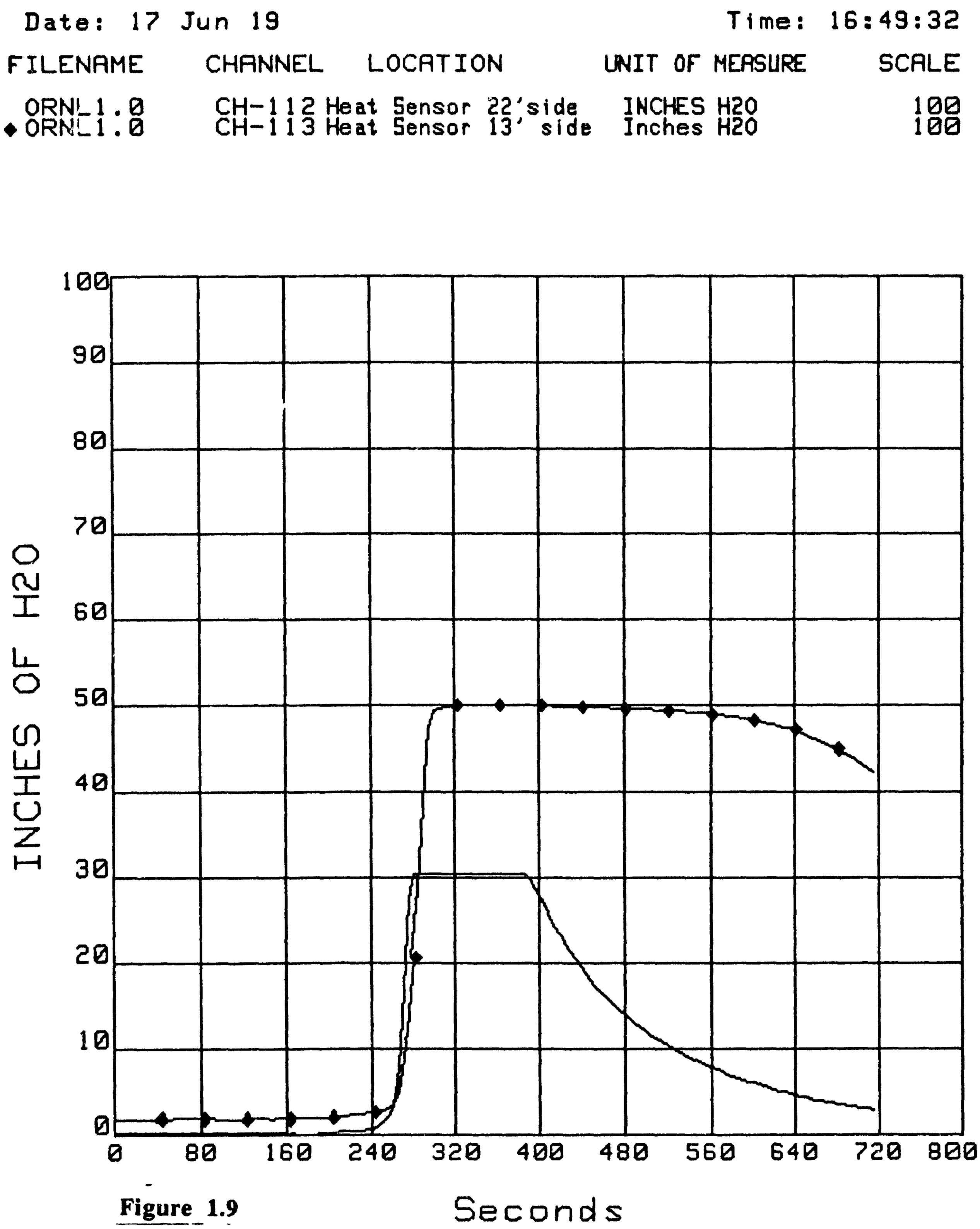

Date: 17 Jun 19
Time: 16:49:32
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL1.0 CH-80 O2 6' UP % O2 24
◆ ORNL1.0 CH-81 CO2 6' UP % CO2 12
× ORNL1.0 CH-82 CO 6' UP % CO 1.2
● ORNL1.0 CH-83 HC 6' UP PPM (=CH4) 15000
PERCENT OF FULL SCALE
0 10 20 30 40 50 60 70 80 90 100
0 80 160 240 320 400 480 560 640 720 800
Seconds

Figure 1.8



Date: 17 Jun 19
Time: 16:49:32
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL1.0 CH-112 Heat Sensor 22'side INCHES H20 100
◆ ORNL1.0 CH-113 Heat Sensor 13' side Inches H20 100
INCHES OF H2O
0 10 20 30 40 50 60 70 80 90 100
0 80 160 240 320 400 480 560 640 720 800
Seconds

Figure 1.9

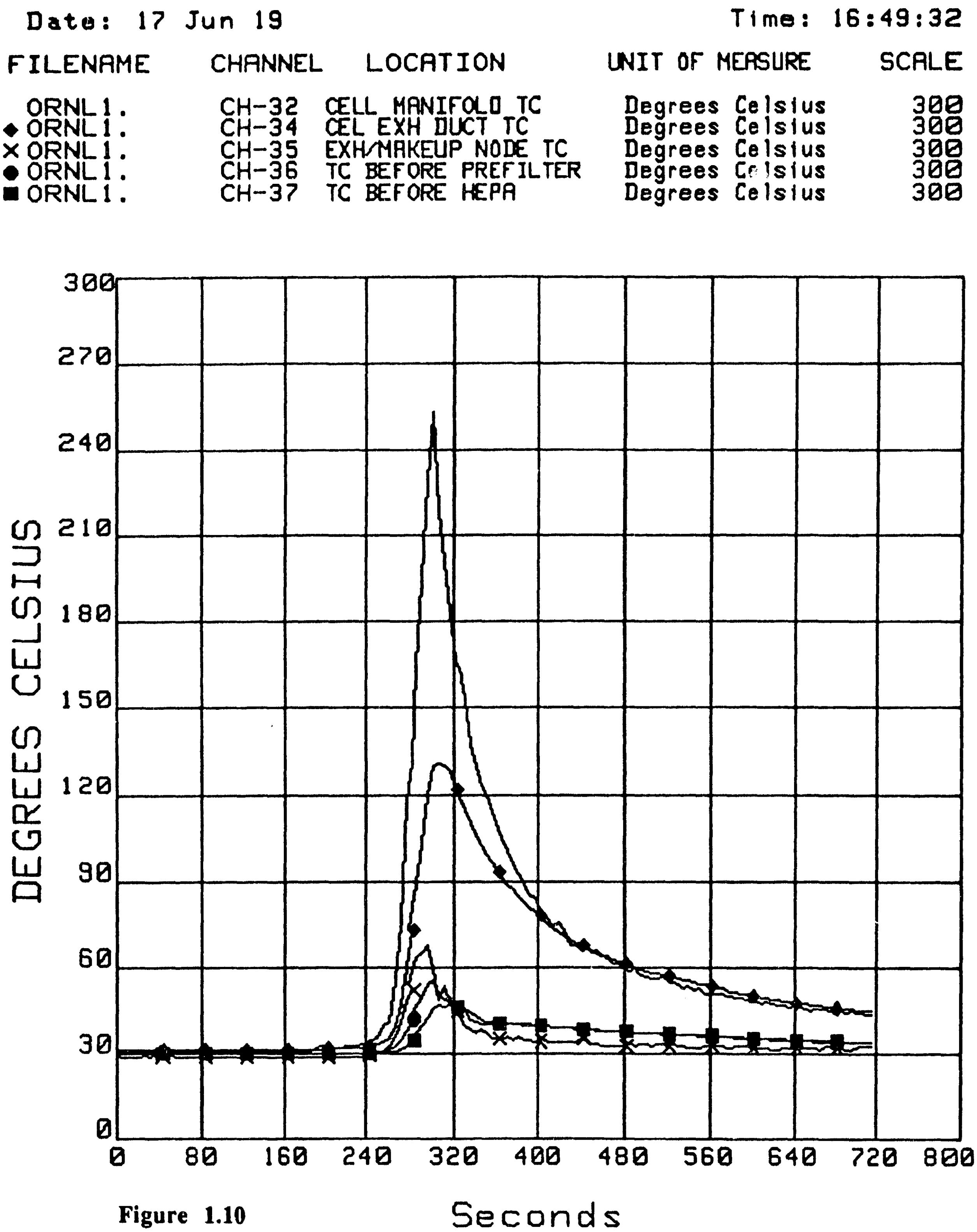

Date: 17 Jun 19
Time: 16:49:32
FILENAME
CHANNEL
LOCATION
UNIT OF MEASURE
SCALE
ORNL1. CH-32 CELL MANIFOLD TC Degrees Celsius 300
ORNL1. CH-34 CEL EXH DUCT TC Degrees Celsius 300
ORNL1. CH-35 EXH/MAKEUP NODE TC Degrees Celsius 300
ORNL1. CH-36 TC BEFORE PREFILTER Degrees Celsius 300
ORNL1. CH-37 TC BEFORE HEPA Degrees Celsius 300
DEGREES CELSIUS
0
30
60
90
120
150
180
210
240
270
300
0
80
160
240
320
400
480
560
640
720
800
Seconds

Figure 1.10

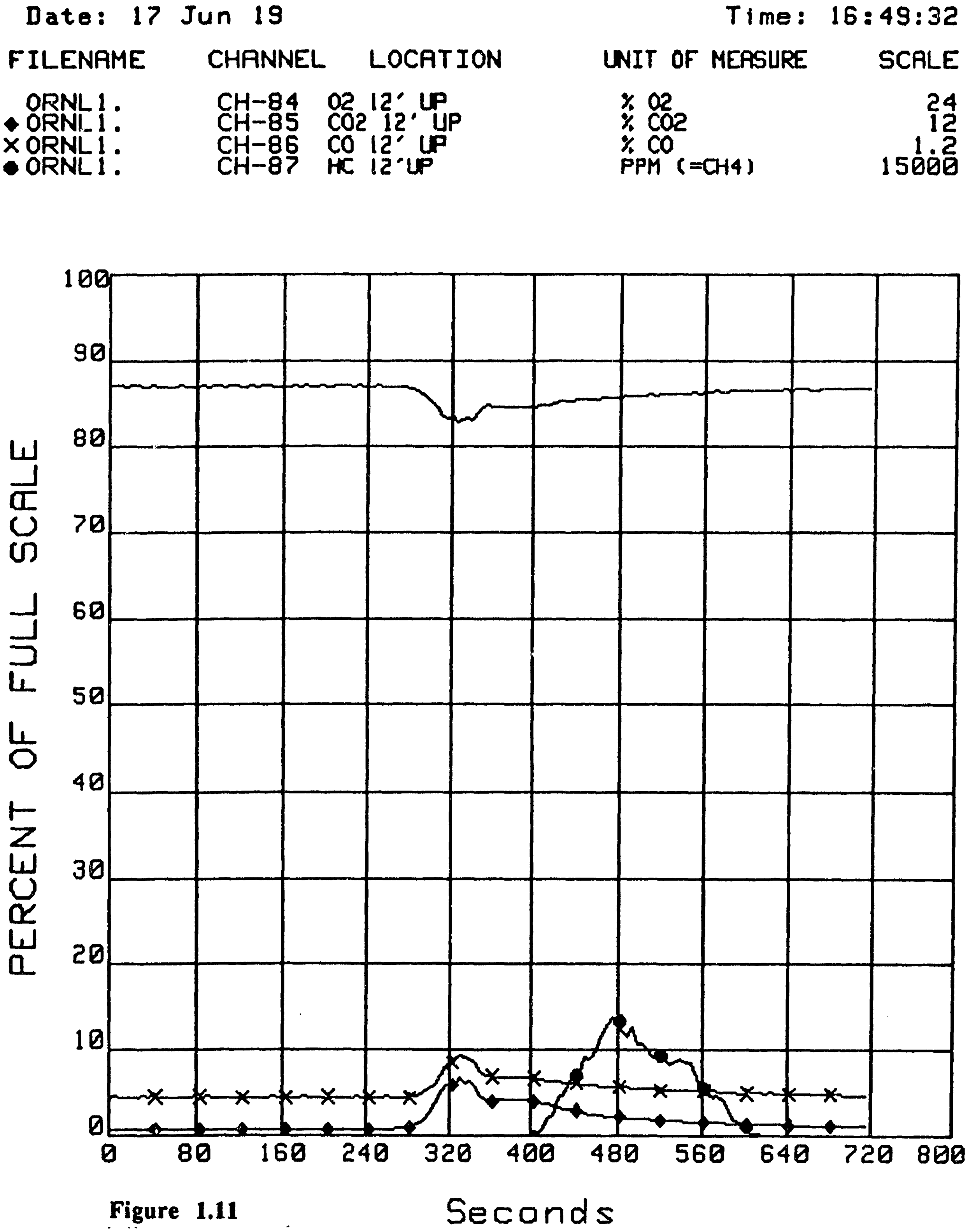

Date: 17 Jun 19
Time: 16:49:32
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL1. CH-84 O2 12' UP % O2 24
ORNL1. CH-85 CO2 12' UP % CO2 12
ORNL1. CH-86 CO 12' UP % CO 1.2
ORNL1. CH-87 HC 12'UP PPM (=CH4) 15000
PERCENT OF FULL SCALE
0
10
20
30
40
50
60
70
80
90
100
0 80 160 240 320 400 480 560 640 720 800
Seconds

Figure 1.11

Date: 17 Jun 19 Time: 16:49:32

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL1.	CH-88	O2 Duct Node	% O2	24
◆ORNL1.	CH-89	CO2 Duct Node	% CO2	12
×ORNL1.	CH-90	CO Duct Node	% CO	1.2
●ORNL1.	CH-91	HC Duct Node	PPM (=CH4)	15000

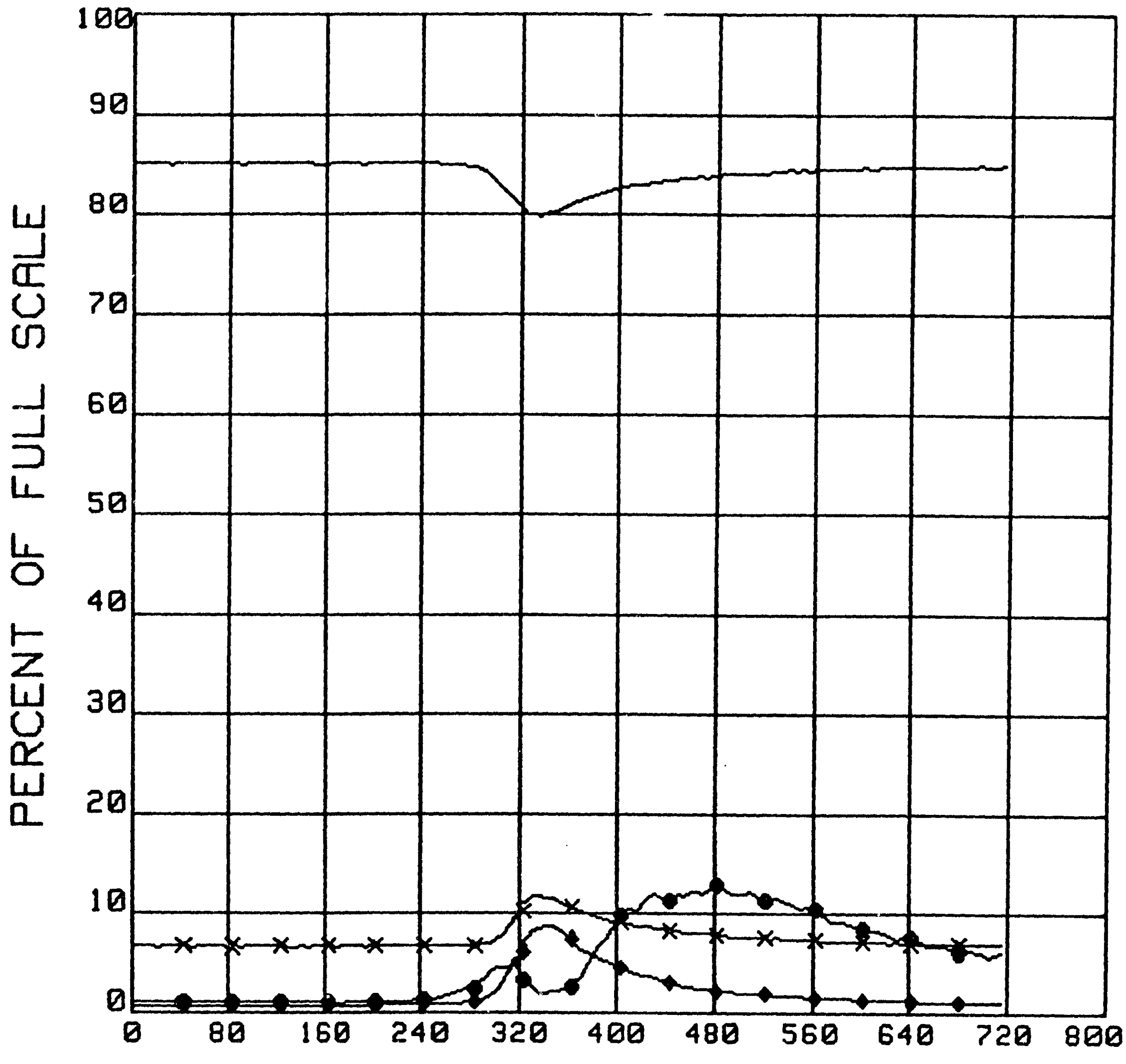


Figure 1.12

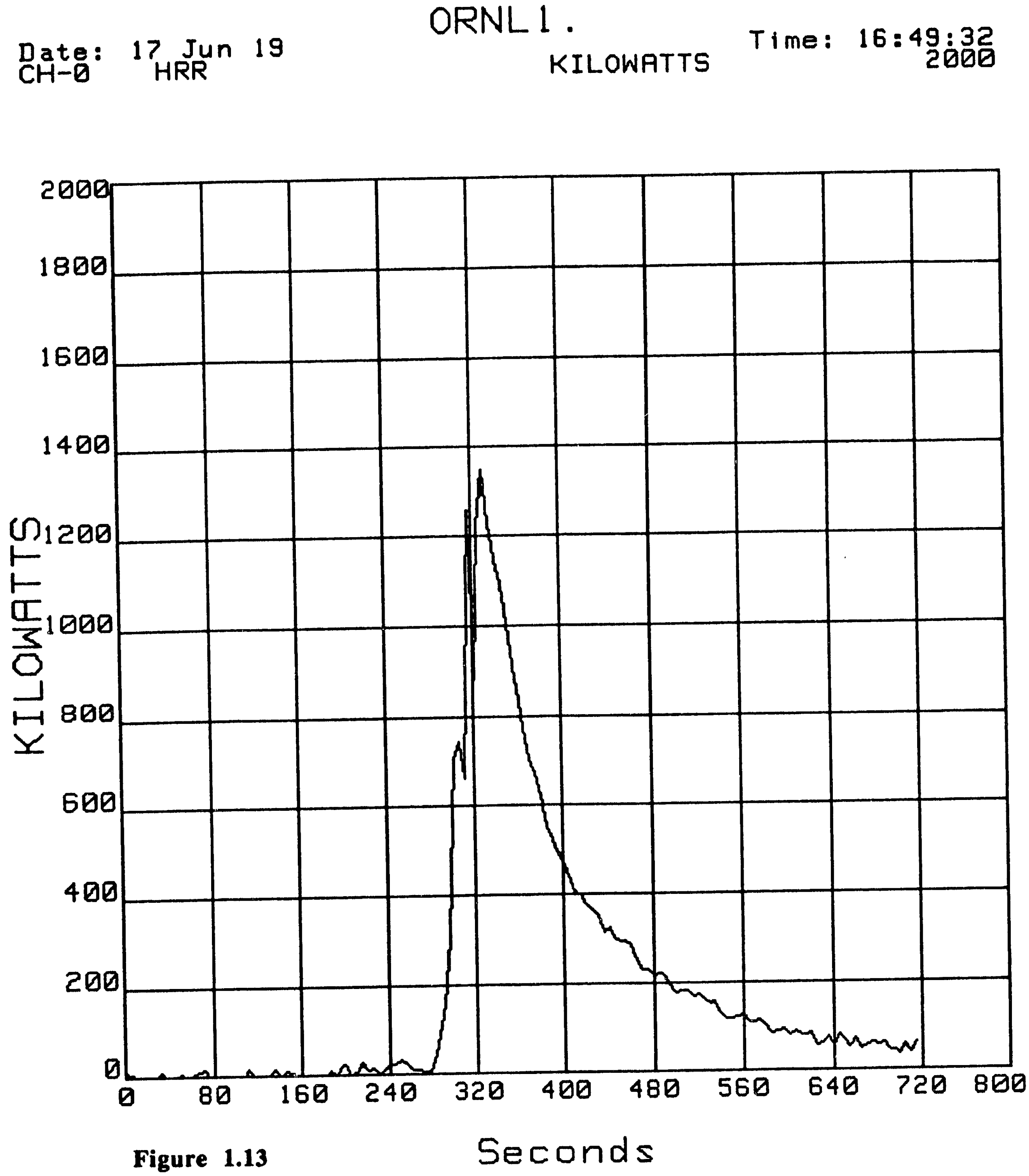


Figure 1.13

No. of channels=73

Date: 17 Jun 19 Time: 16:49:32

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL1.	CH-102	Inlet A/F (TFM)	CFM	5000
◆ ORNL1.	CH-80	O2 6' UP	% O2	24
× ORNL1.	CH-84	O2 12' UP	% O2	24
● ORNL1.	CH-88	O2 Duct Node	% O2	24

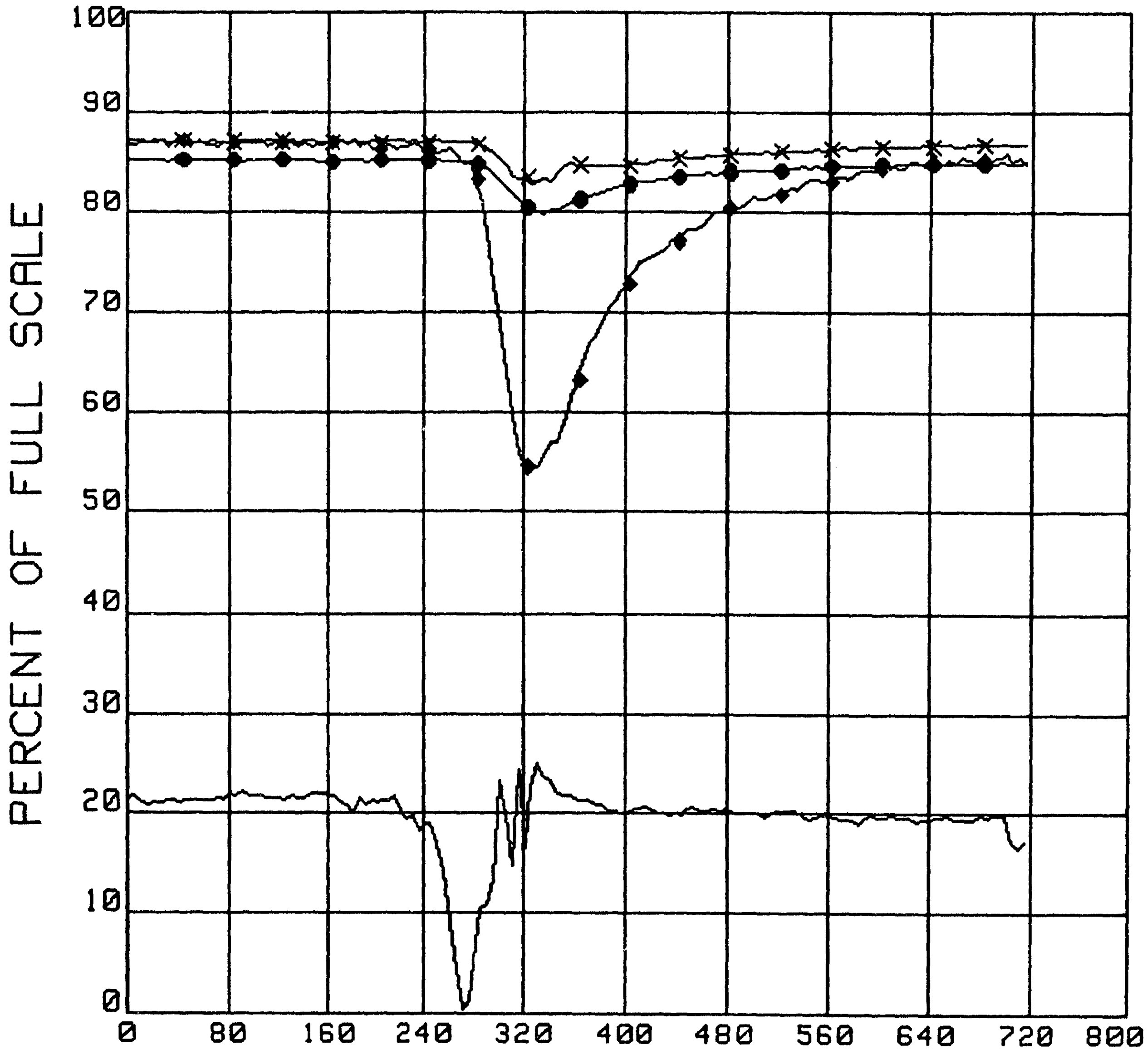


Figure 1.14

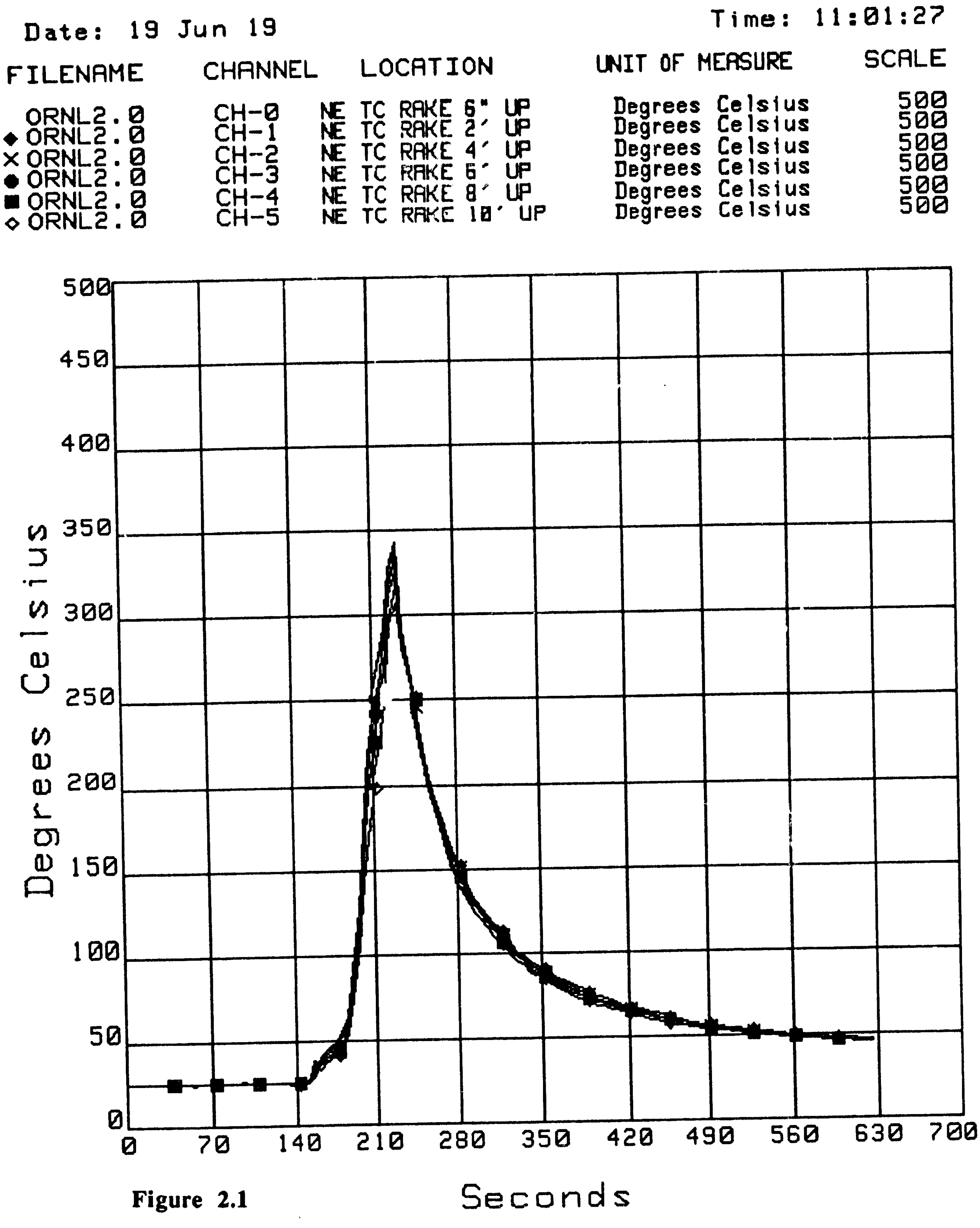

Date: 19 Jun 19
Time: 11:01:27
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL2.0 CH-0 NE TC RAKE 6" UP Degrees Celsius 500
ORNL2.0 CH-1 NE TC RAKE 2' UP Degrees Celsius 500
ORNL2.0 CH-2 NE TC RAKE 4' UP Degrees Celsius 500
ORNL2.0 CH-3 NE TC RAKE 6' UP Degrees Celsius 500
ORNL2.0 CH-4 NE TC RAKE 8' UP Degrees Celsius 500
ORNL2.0 CH-5 NE TC RAKE 10' UP Degrees Celsius 500
Degrees Celsius
0
50
100
150
200
250
300
350
400
450
500
0
70
140
210
280
350
420
490
560
630
700
Seconds

Figure 2.1

Date: 19 Jun 19 Time: 11:01:27

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL2.0	CH-6	NE TC RAKE 12' UP	Degrees Celsius	500
◆ ORNL2.0	CH-7	NE TC RAKE 14' UP	Degrees Celsius	500
× ORNL2.0	CH-8	NE TC RAKE 16' UP	Degrees Celsius	500
● ORNL2.0	CH-9	NE TC RAKE 18' UP	Degrees Celsius	500
■ ORNL2.0	CH-10	NE TC RAKE 20' UP	Degrees Celsius	500
◇ ORNL2.0	CH-11	NE TC RAKE 6" DOWN	Degrees Celsius	500

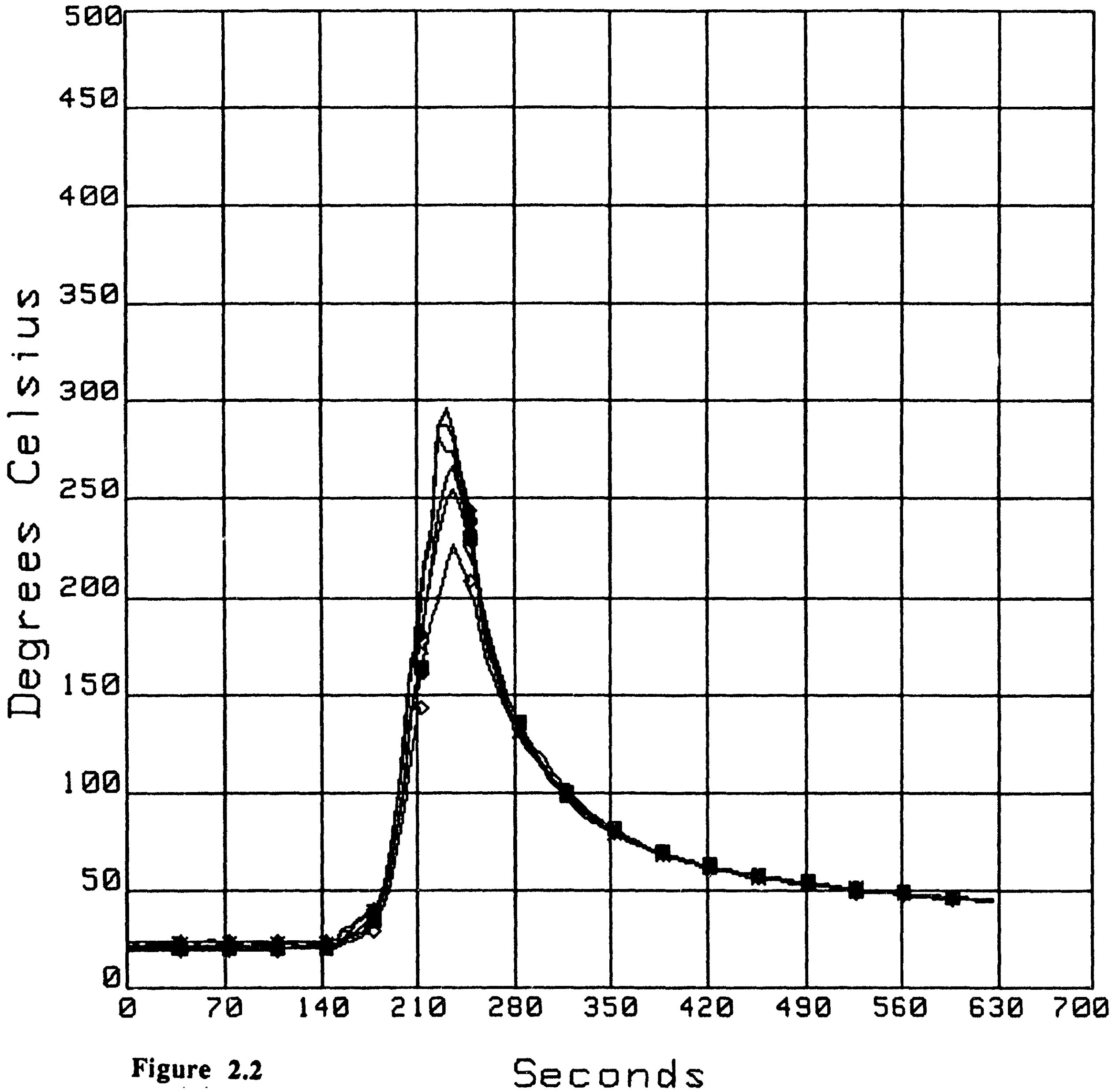


Figure 2.2

Date: 19 Jun 19

Time: 11:01:27

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL2.0	CH-20	So TC RAKE 6" UP	Degrees Celsius	1200
◆ ORNL2.0	CH-21	So TC RAKE 2' UP	Degrees Celsius	1200
× ORNL2.0	CH-22	So TC RAKE 4' UP	Degrees Celsius	1200
● ORNL2.0	CH-23	So TC RAKE 6' UP	Degrees Celsius	1200

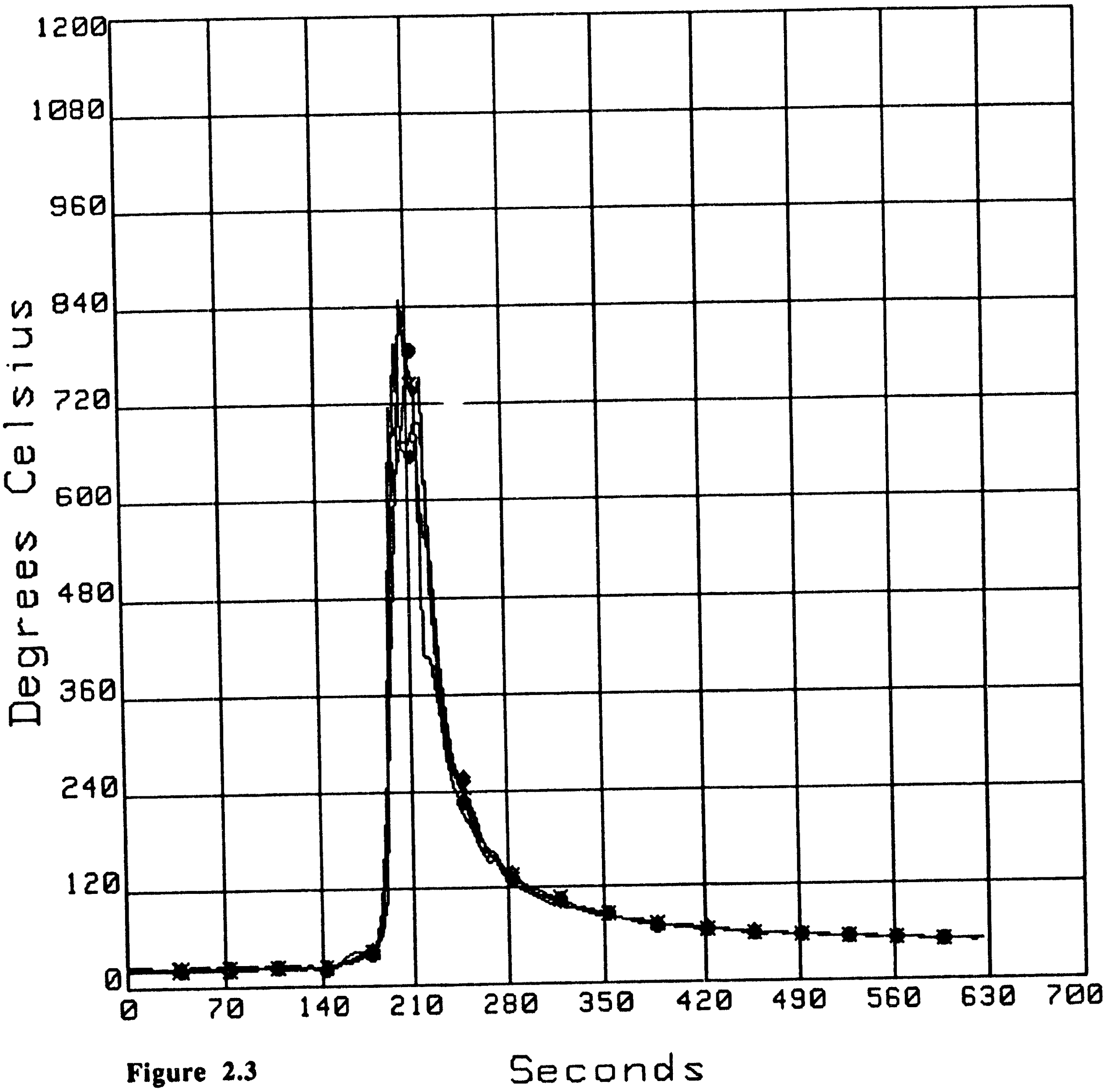


Figure 2.3

Date: 19 Jun 19 Time: 11:01:27

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL2.0	CH-27	TOP So WINDOW TC	Degrees Celsius	500
◆ ORNL2.0	CH-28	TOP No WINDOW TC	Degrees Celsius	500
× ORNL2.0	CH-29	BOTTOM So WINDOW TC	Degrees Celsius	500
● ORNL2.0	CH-30	BOTTOM No WINDOW TC	Degrees Celsius	500

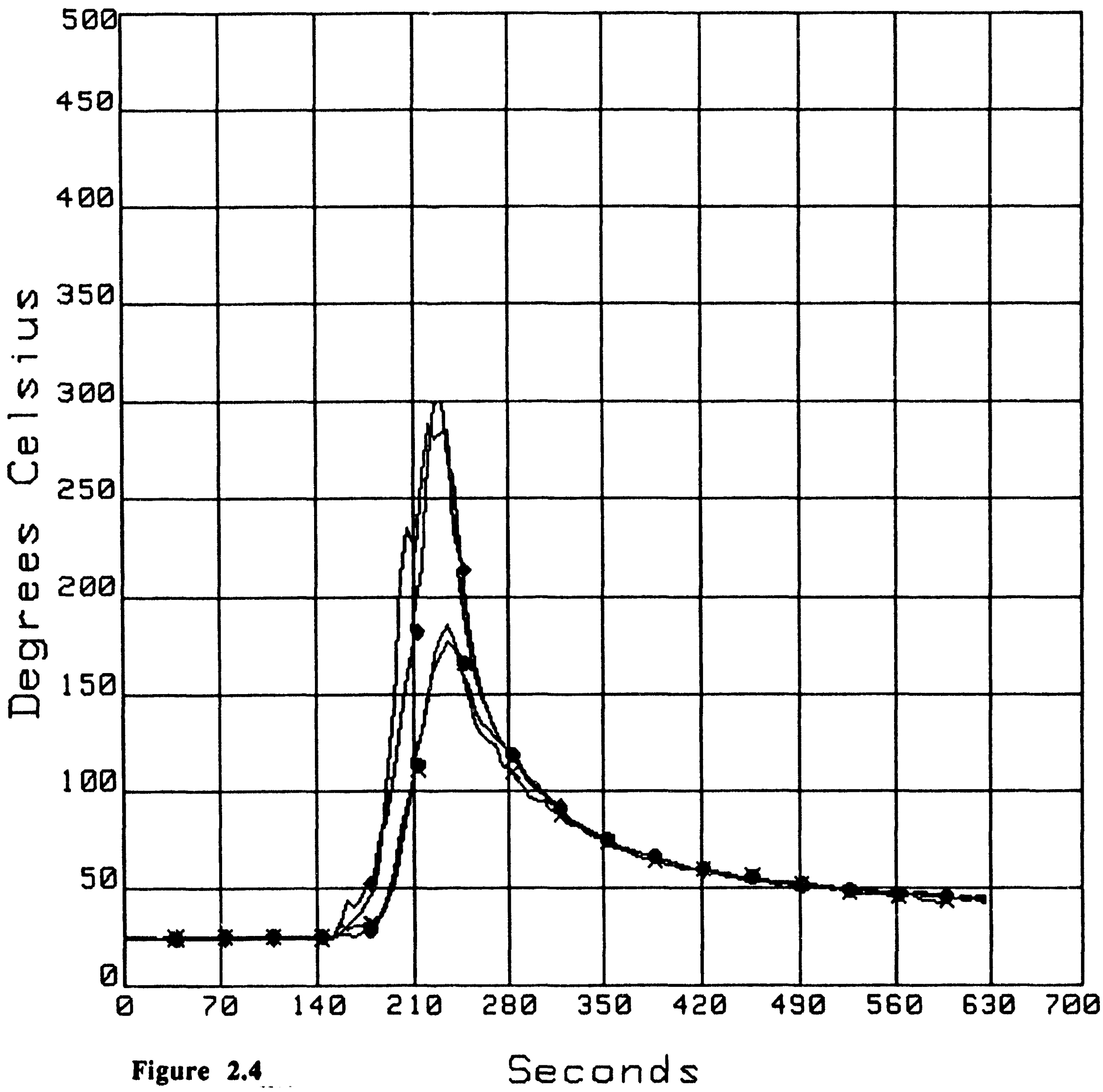


Figure 2.4

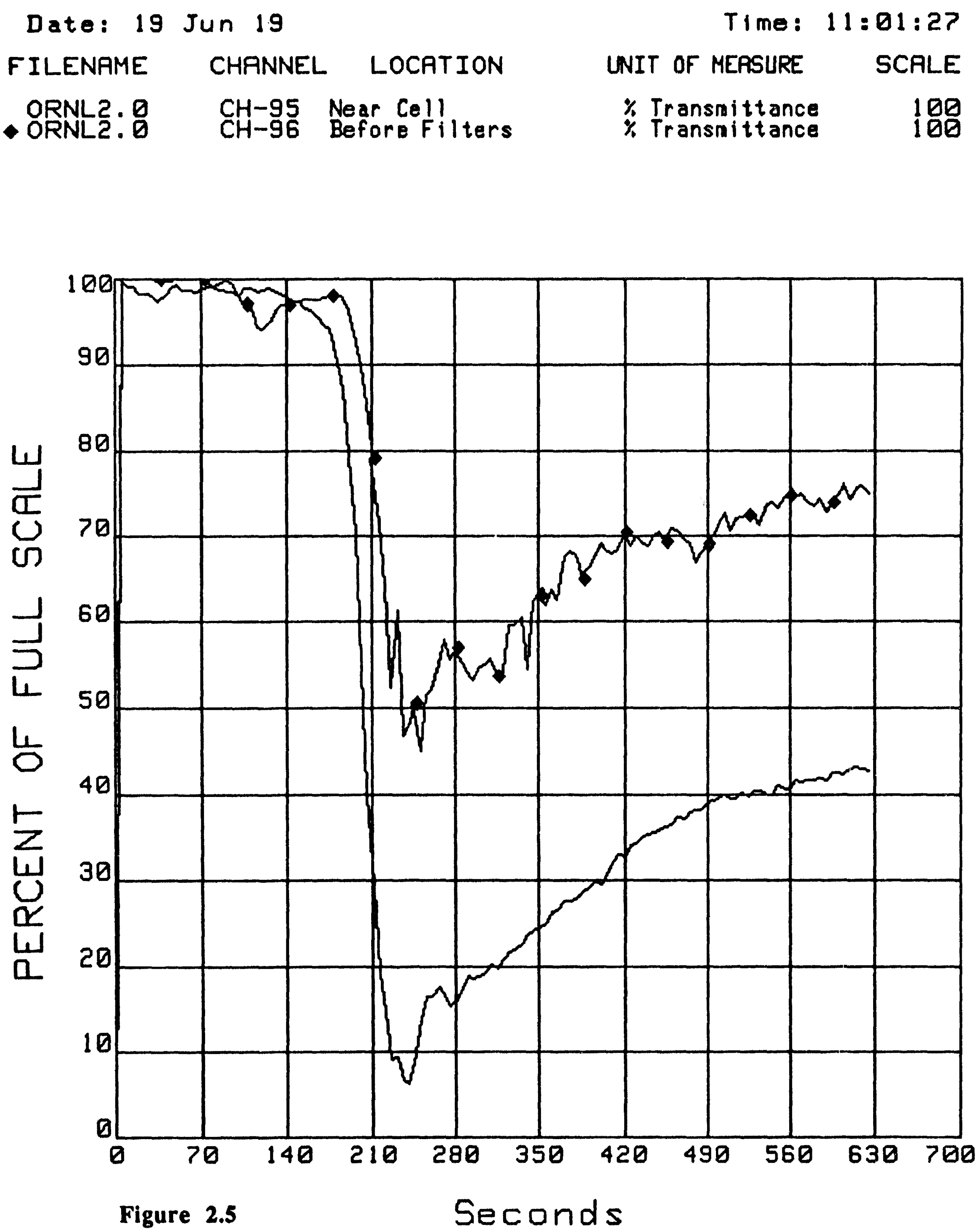

Date: 19 Jun 19
Time: 11:01:27
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL2.0 CH-95 Near Cell % Transmittance 100
◆ ORNL2.0 CH-96 Before Filters % Transmittance 100
PERCENT OF FULL SCALE
100
90
80
70
60
50
40
30
20
10
0
0 70 140 210 280 350 420 490 560 630 700
Seconds

Figure 2.5

Date: 19 Jun 19 Time: 11:01:27

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL2.0	CH-102	Inlet A/F (TFM)	CFM	5000
◆ ORNL2.0	CH-104	Exit A/F (Pitot)	CFM	5000
× ORNL2.0	CH-105	Exit A/F (TFM)	CFM	5000

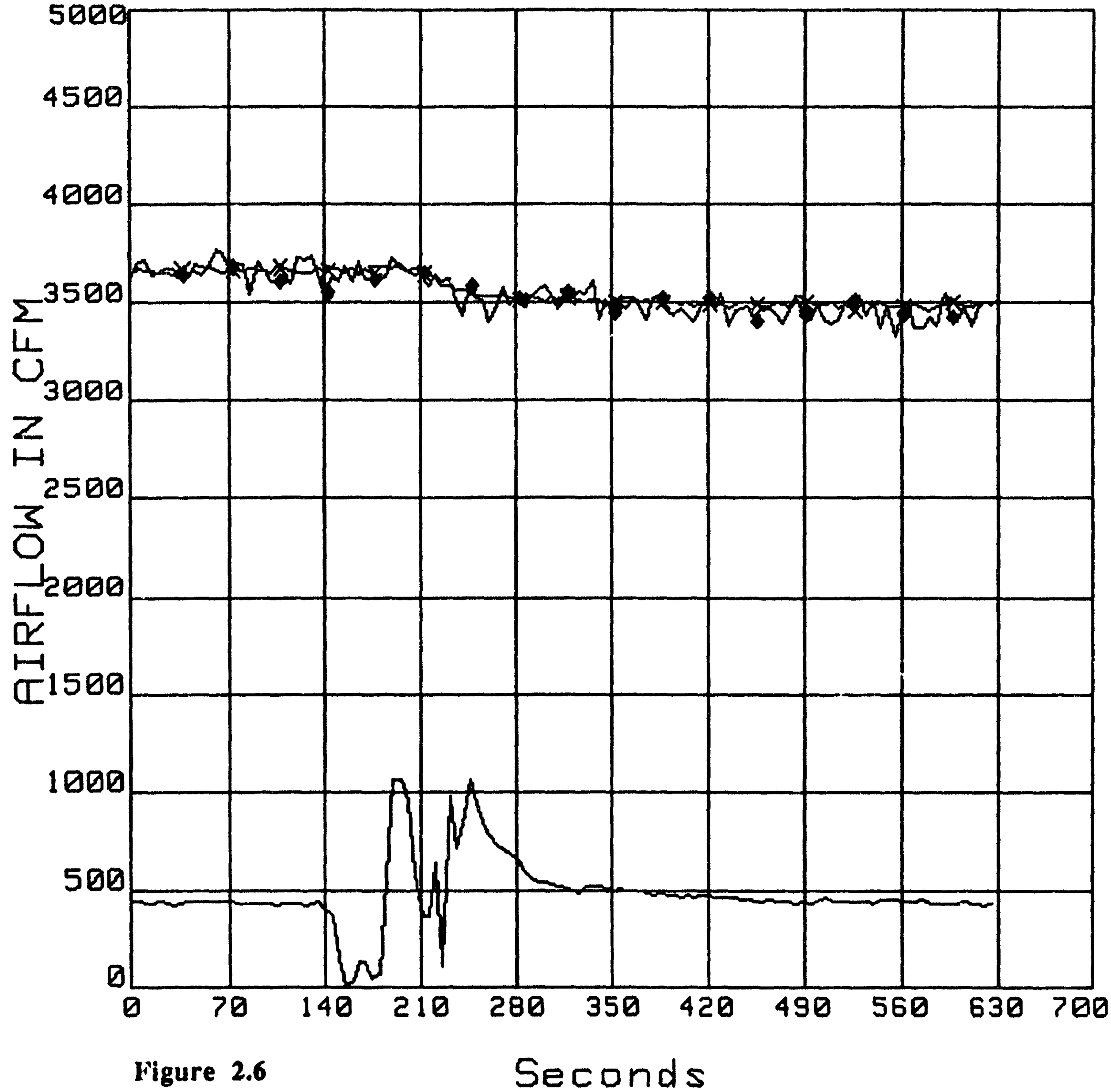


Figure 2.6

Date: 19 Jun 19 Time: 11:01:27

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL2.0	CH-95	Near Cell	% Transmittance	100
◆ ORNL2.0	CH-96	Before Filters	% Transmittance	100

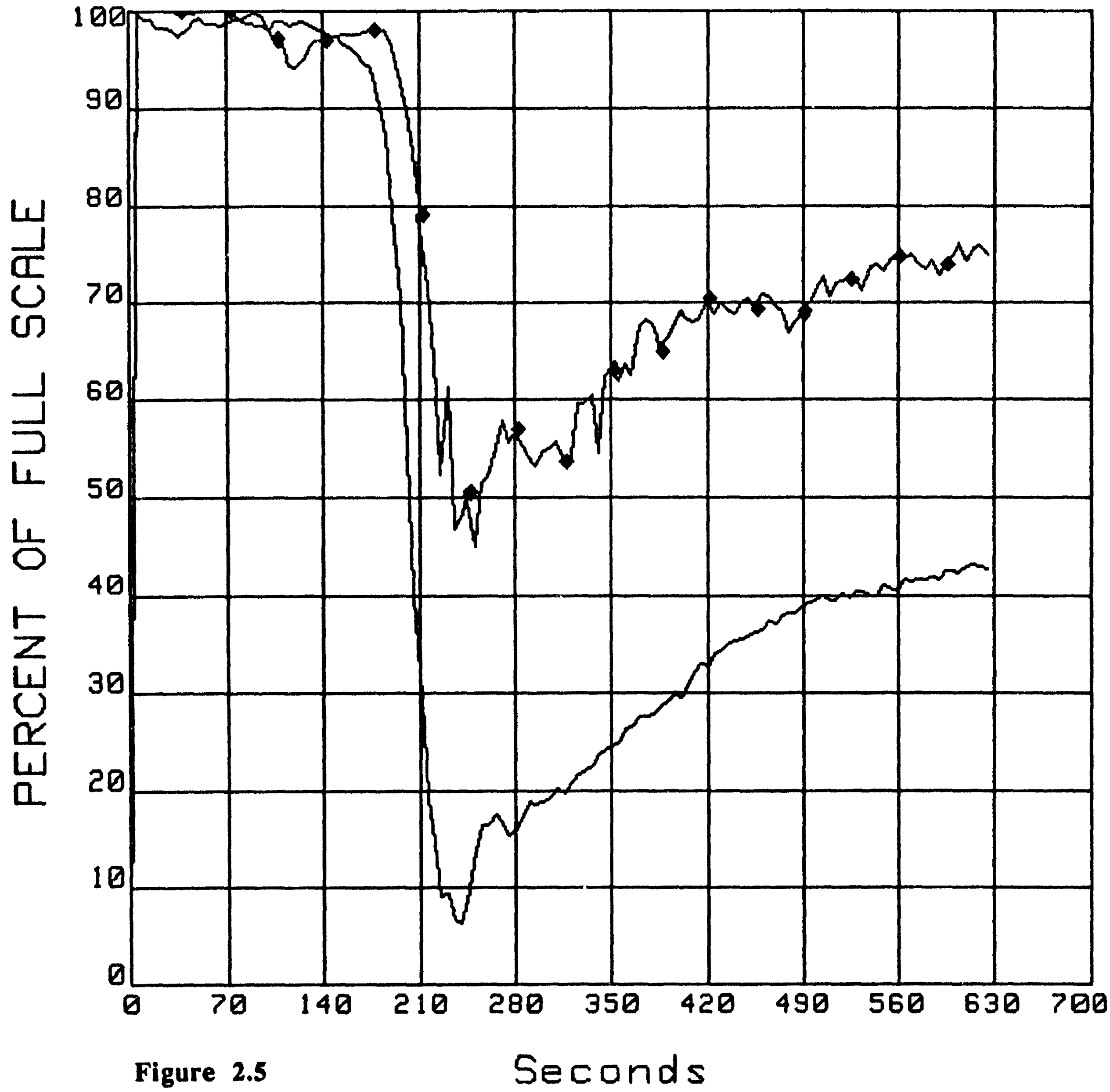


Figure 2.5

Date: 19 Jun 19 Time: 11:01:27

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL2.0	CH-102	Inlet A/F (TFM)	CFM	5000
◆ ORNL2.0	CH-104	Exit A/F (Pitot)	CFM	5000
× ORNL2.0	CH-105	Exit A/F (TFM)	CFM	5000

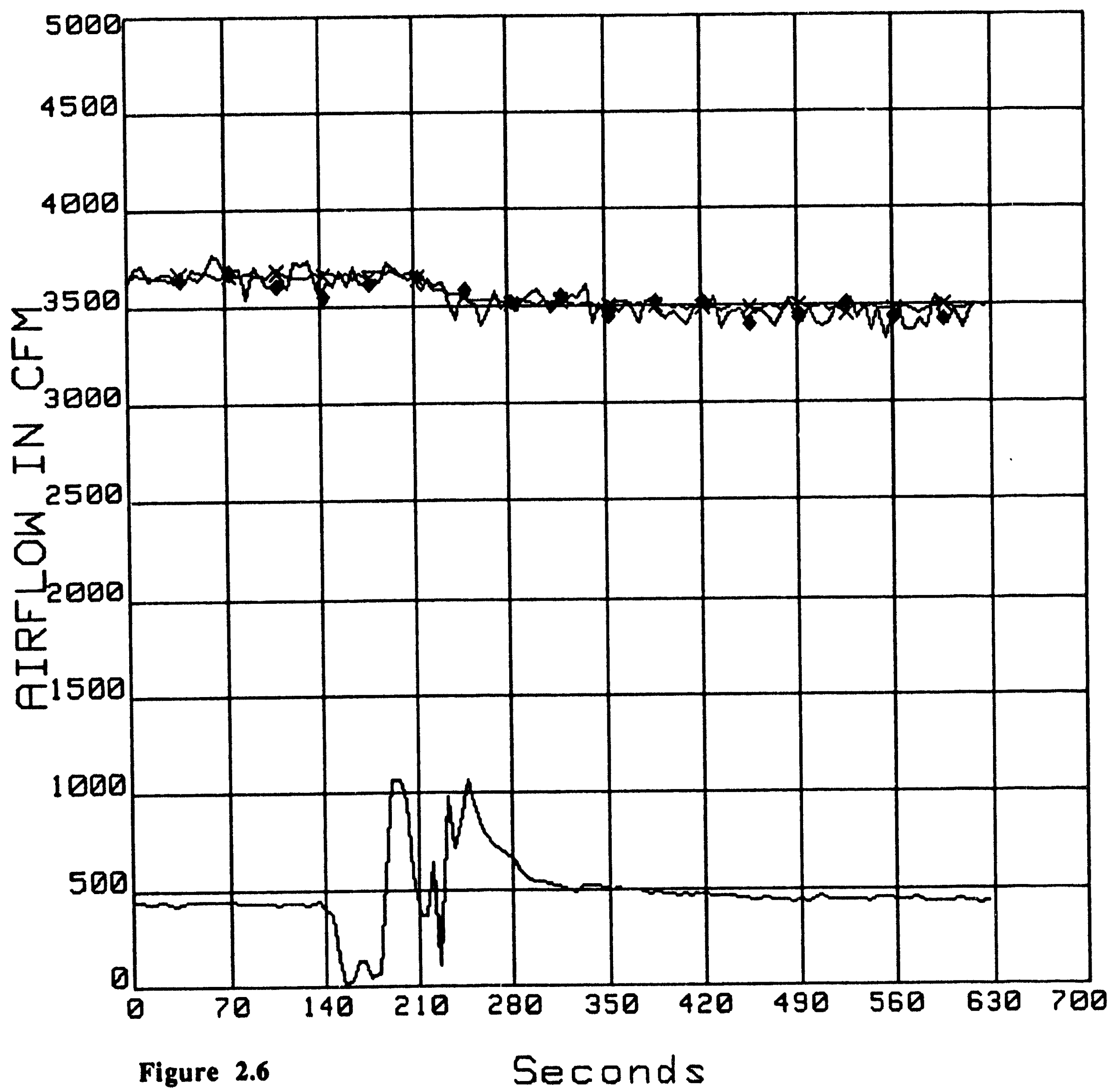


Figure 2.6

Date: 19 Jun 19 | Time: 11:01:27

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL2.0	CH-109	Delta P HEPA	INCHES H20	5
◆ ORNL2.0	CH-110	Delta P PreFilter	INCHES H20	5

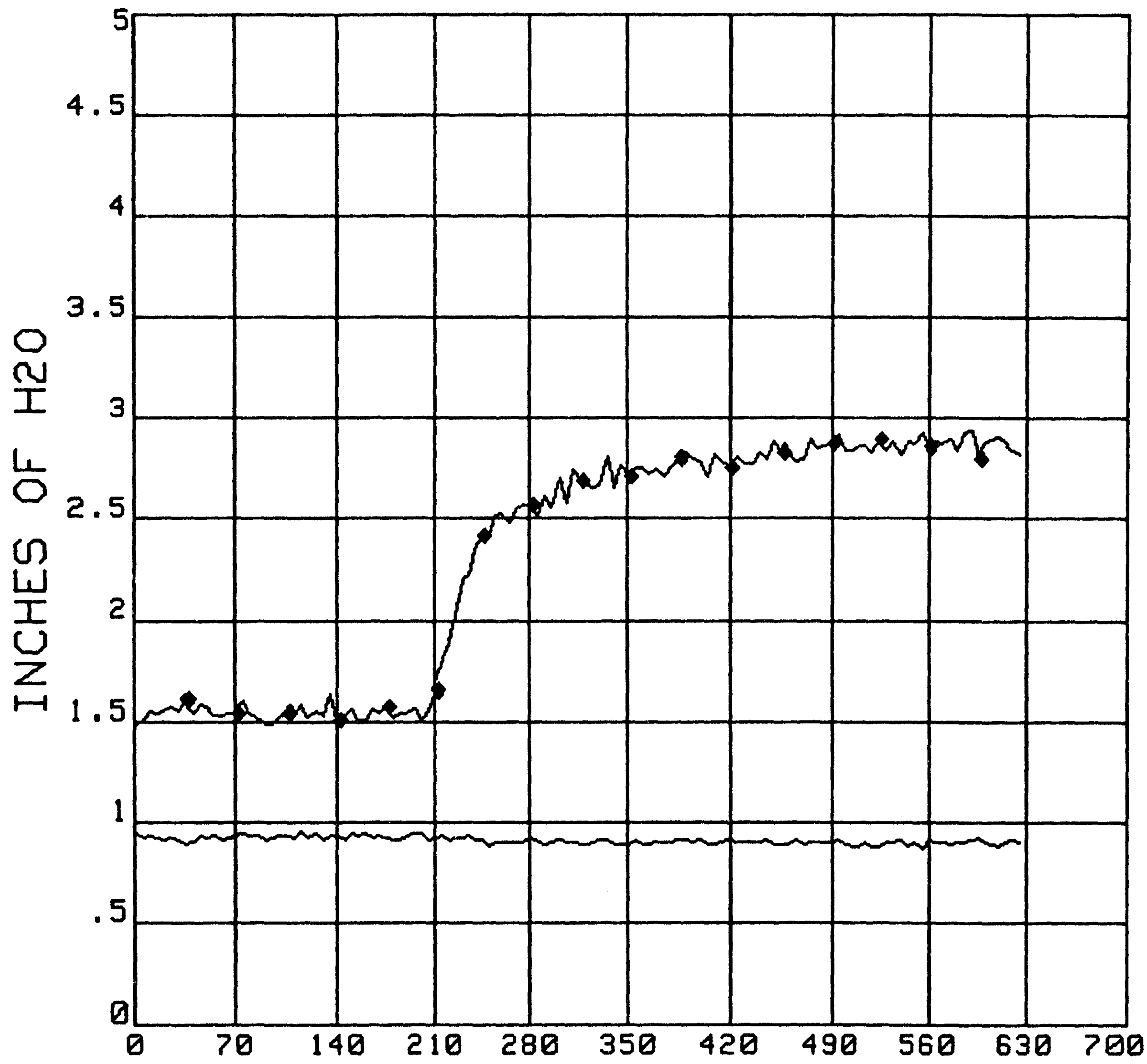


Figure 2.7

Date: 19 Jun 19 Time: 11:01:27

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL2.0	CH-80	O2 6´ UP	% O2	25
◆ ORNL2.0	CH-81	CO2 6´ UP	% CO2	12
× ORNL2.0	CH-82	CO 6´ UP	% CO	1.5
● ORNL2.0	CH-83	HC 6´ UP	PPM (=CH4)	25000

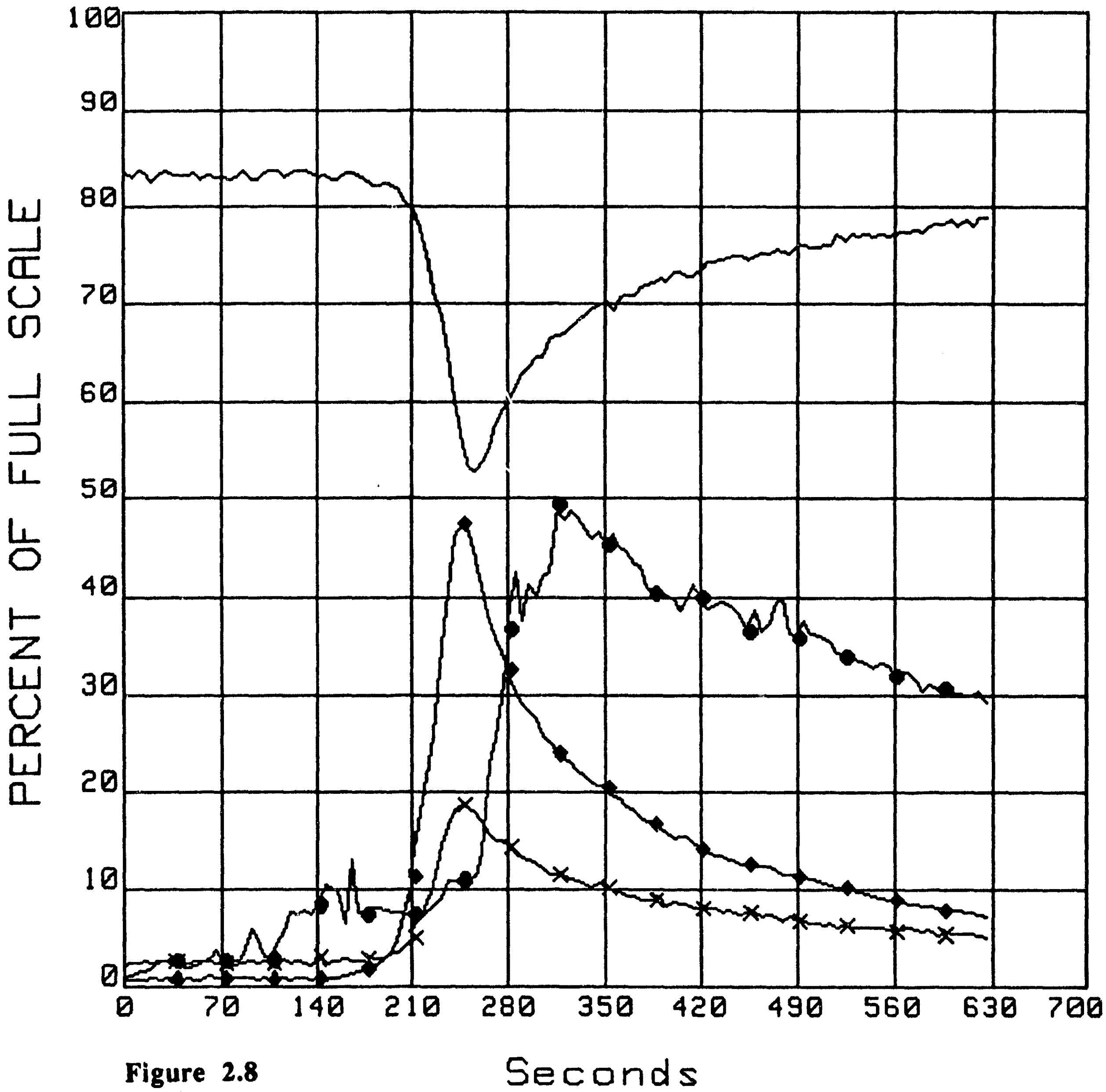


Figure 2.8

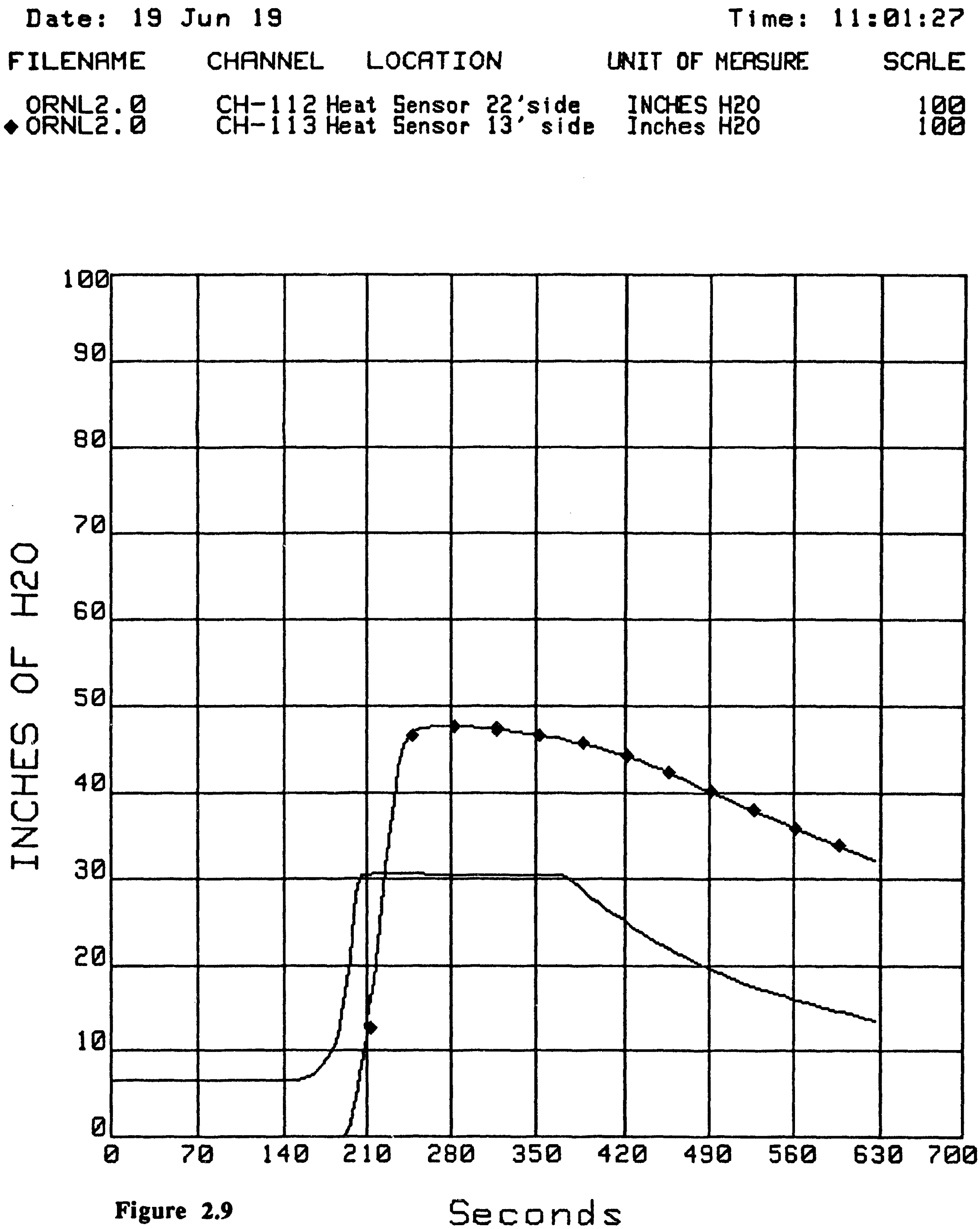

Date: 19 Jun 19
Time: 11:01:27
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL2.0 CH-112 Heat Sensor 22'side INCHES H20 100
◆ ORNL2.0 CH-113 Heat Sensor 13' side Inches H20 100
INCHES OF H2O
100
90
80
70
60
50
40
30
20
10
0
0
70
140
210
280
350
420
490
560
630
700
Seconds

Figure 2.9

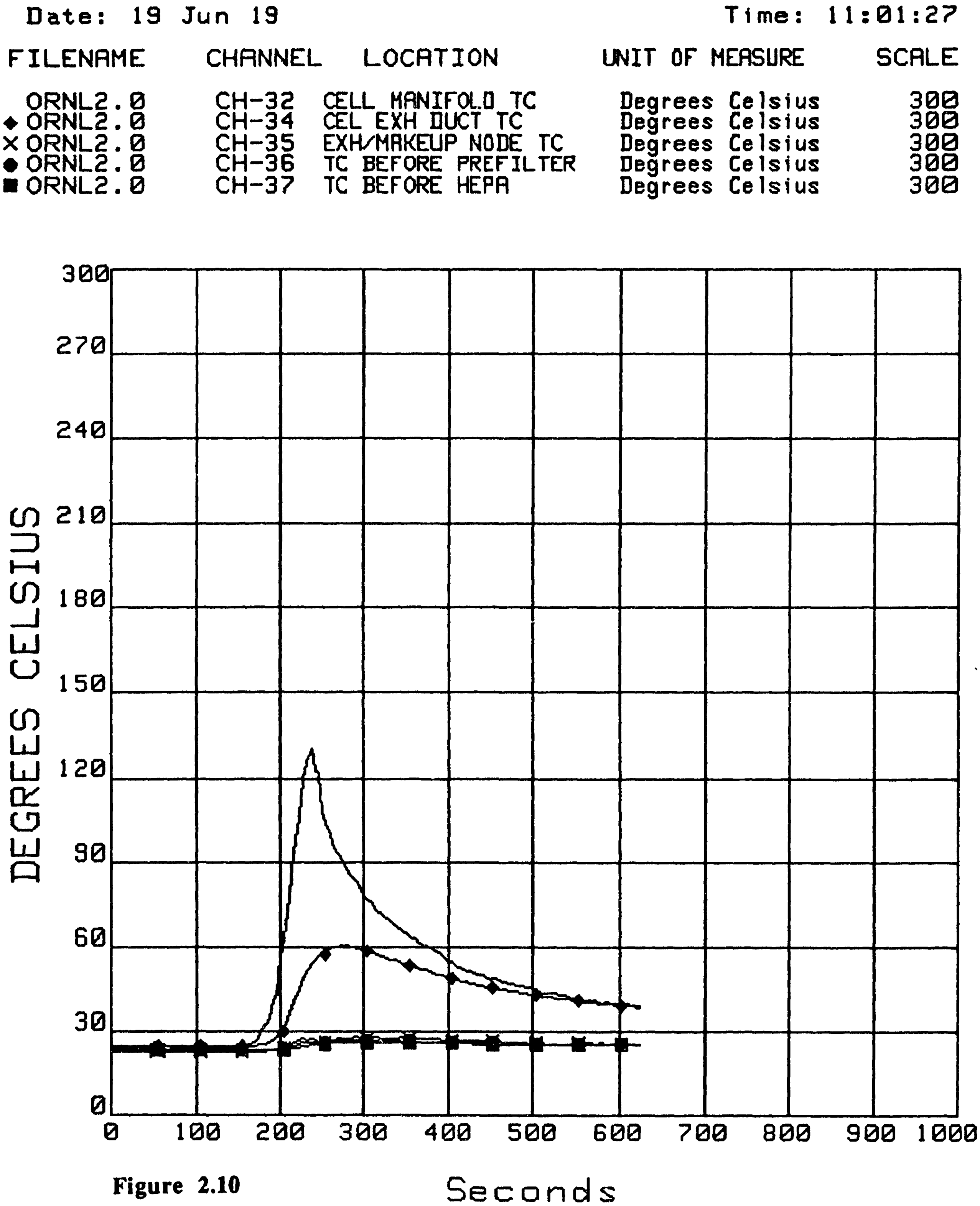

Date: 19 Jun 19
Time: 11:01:27
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL2.0 CH-32 CELL MANIFOLD TC Degrees Celsius 300
◆ ORNL2.0 CH-34 CEL EXH DUCT TC Degrees Celsius 300
× ORNL2.0 CH-35 EXH/MAKEUP NODE TC Degrees Celsius 300
● ORNL2.0 CH-36 TC BEFORE PREFILTER Degrees Celsius 300
■ ORNL2.0 CH-37 TC BEFORE HEPA Degrees Celsius 300
DEGREES CELSIUS
300
270
240
210
180
150
120
90
60
30
0
0 100 200 300 400 500 600 700 800 900 1000
Seconds

Figure 2.10

Date: 19 Jun 19 Time: 11:01:27

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL2.0	CH-84	O2 12' UP	% O2	25
◆ ORNL2.0	CH-85	CO2 12' UP	% CO2	12
× ORNL2.0	CH-86	CO 12' UP	% CO	1.5
● ORNL2.0	CH-87	HC 12' UP	PPM (=CH4)	25000

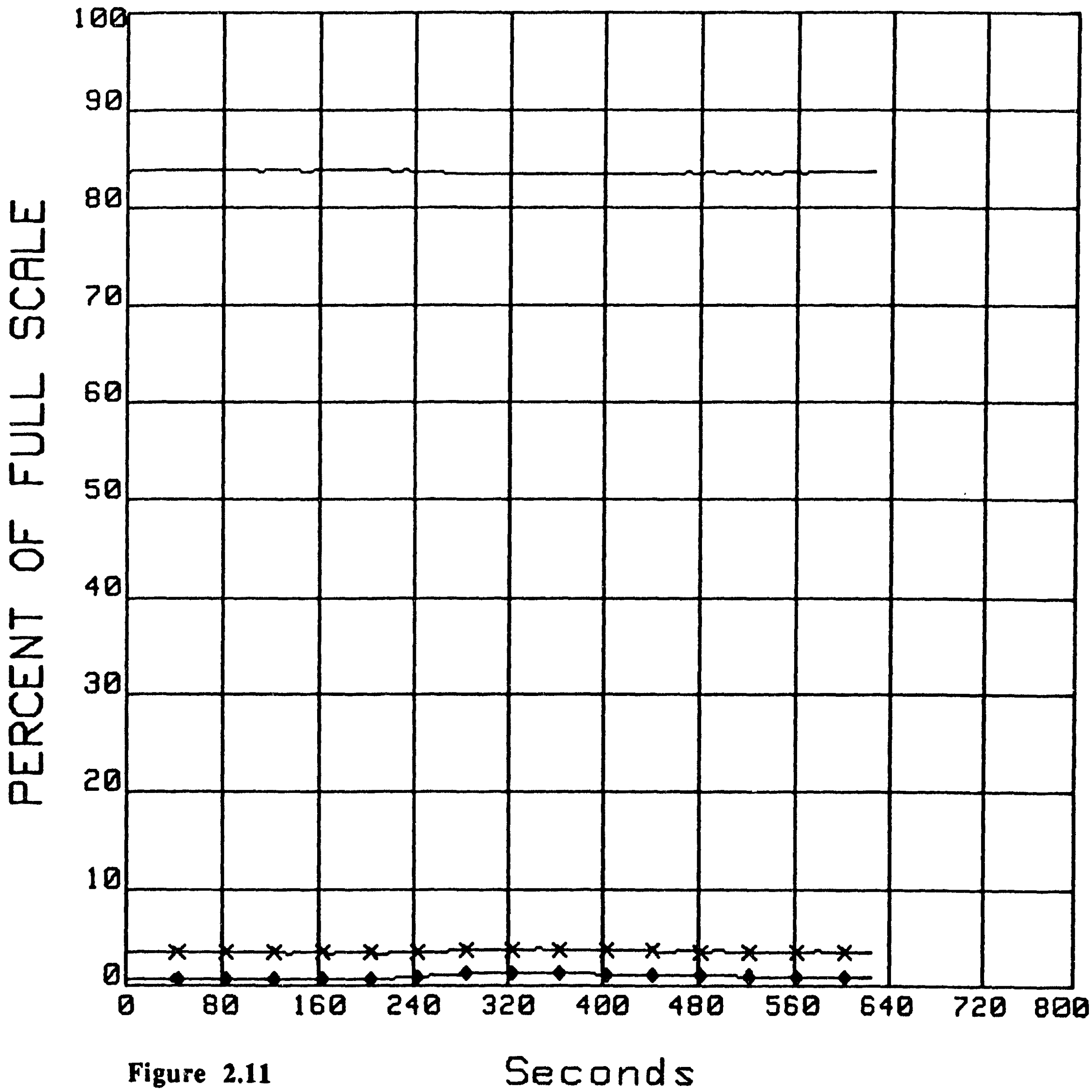


Figure 2.11

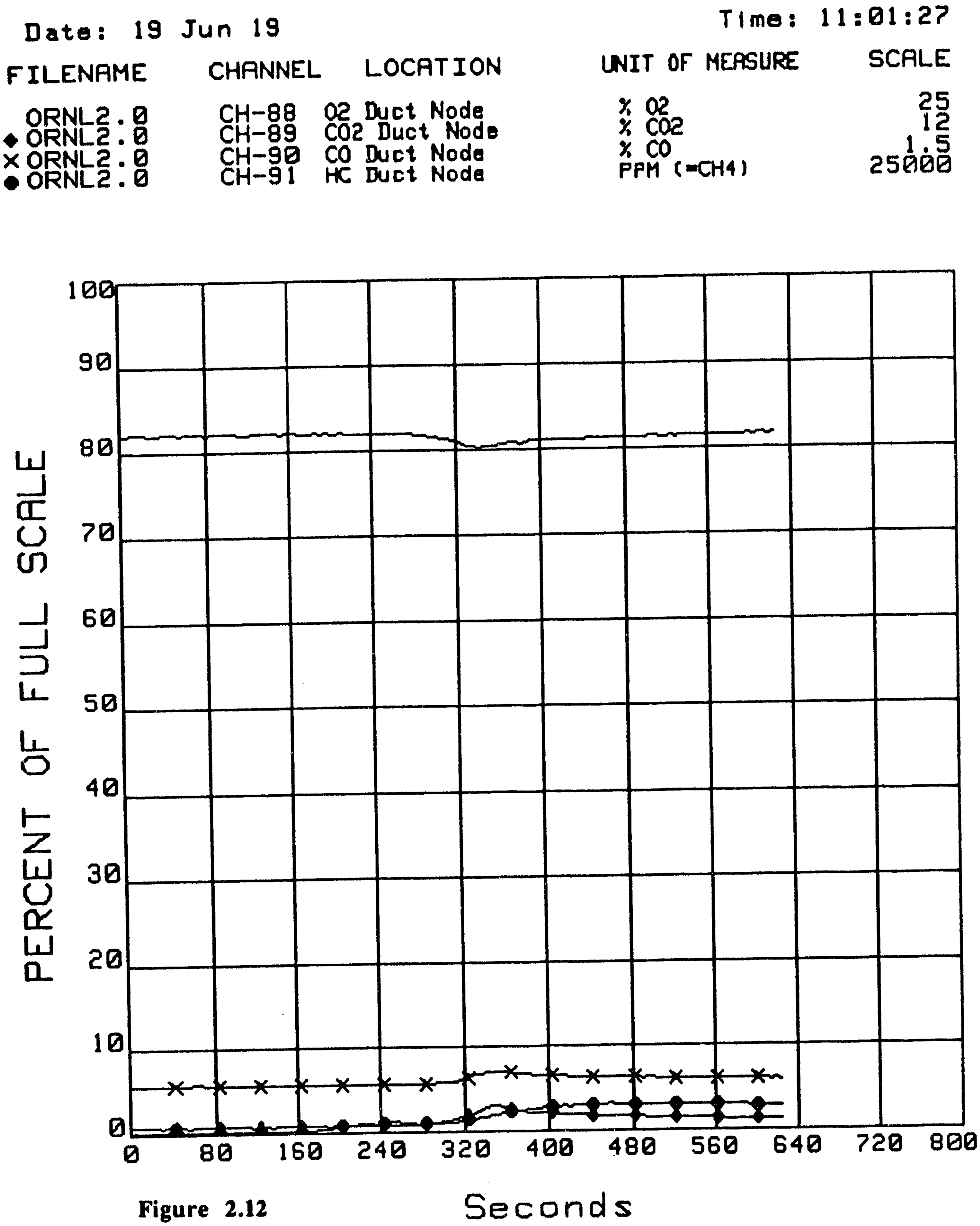

Date: 19 Jun 19
Time: 11:01:27
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL2.0 CH-88 O2 Duct Node % O2 25
◆ ORNL2.0 CH-89 CO2 Duct Node % CO2 12
× ORNL2.0 CH-90 CO Duct Node % CO 1.5
● ORNL2.0 CH-91 HC Duct Node PPM (=CH4) 25000
PERCENT OF FULL SCALE
0
10
20
30
40
50
60
70
80
90
100
0 80 160 240 320 400 480 560 640 720 800
Seconds

Figure 2.12

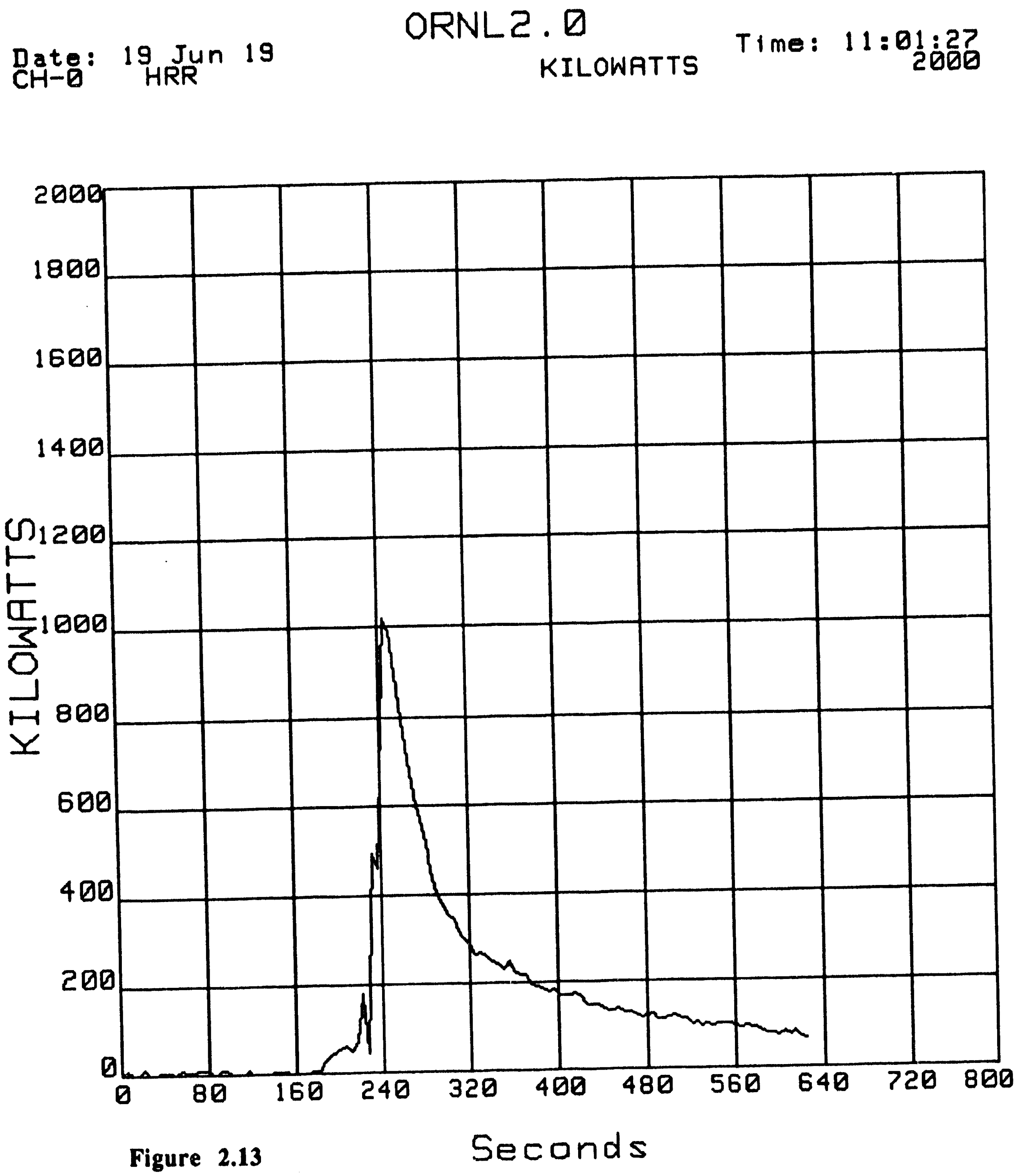


Figure 2.13

No. of channels=73

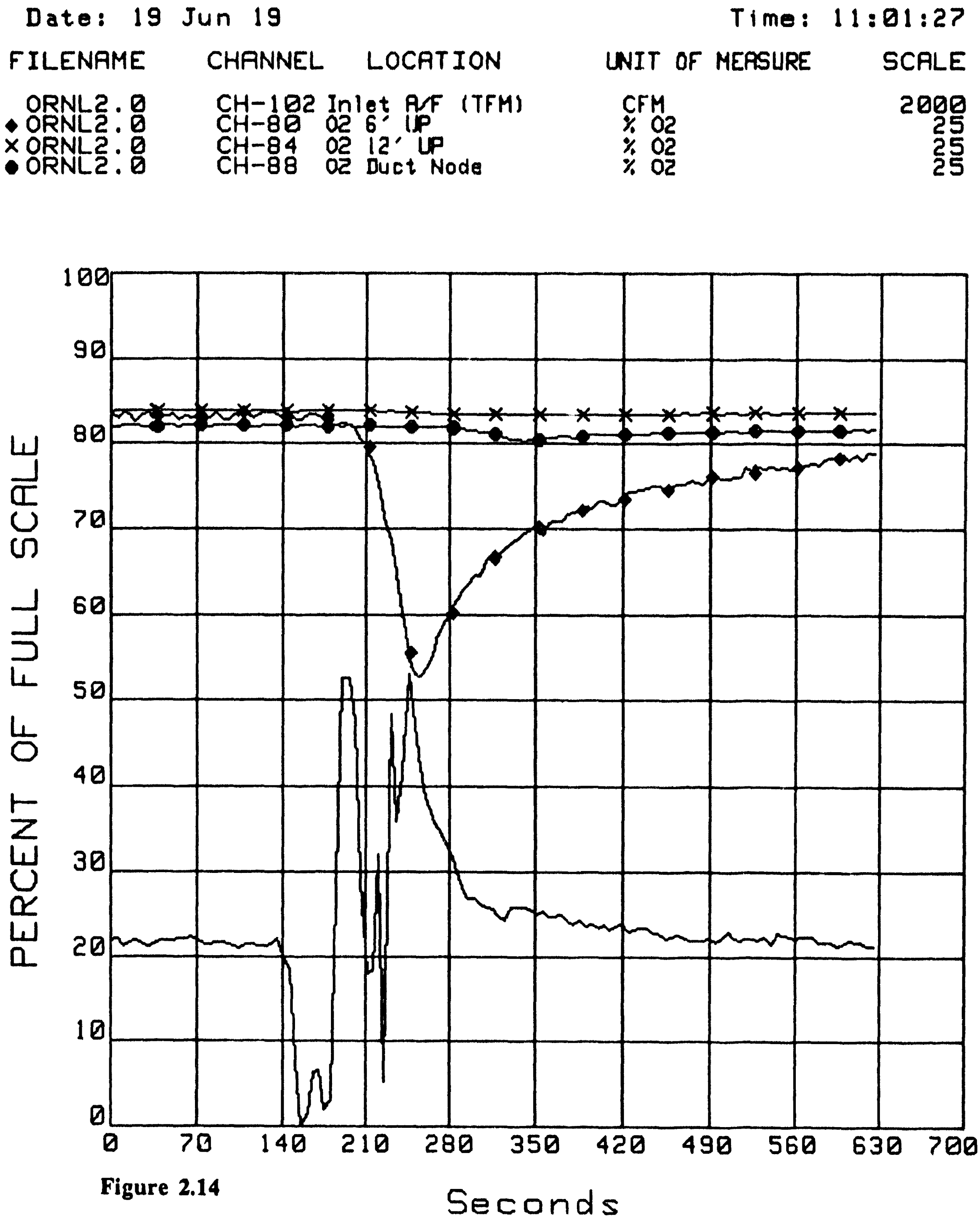

Date: 19 Jun 19
Time: 11:01:27
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL2.0 CH-102 Inlet A/F (TFM) CFM 2000
ORNL2.0 CH-80 02 6' UP % 02 25
ORNL2.0 CH-84 02 12' UP % 02 25
ORNL2.0 CH-88 02 Duct Node % 02 25
PERCENT OF FULL SCALE
100
90
80
70
60
50
40
30
20
10
0
0 70 140 210 280 350 420 490 560 630 700
Seconds

Figure 2.14

Date: 23 Jun 19 Time: 11:01:02

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL3.0	CH-0	NE TC RAKE 6" UP	Degrees Celsius	500
◆ ORNL3.0	CH-1	NE TC RAKE 2' UP	Degrees Celsius	500
× ORNL3.0	CH-2	NE TC RAKE 4' UP	Degrees Celsius	500
● ORNL3.0	CH-3	NE TC RAKE 6' UP	Degrees Celsius	500
■ ORNL3.0	CH-4	NE TC RAKE 8' UP	Degrees Celsius	500
◇ ORNL3.0	CH-5	NE TC RAKE 10' UP	Degrees Celsius	500

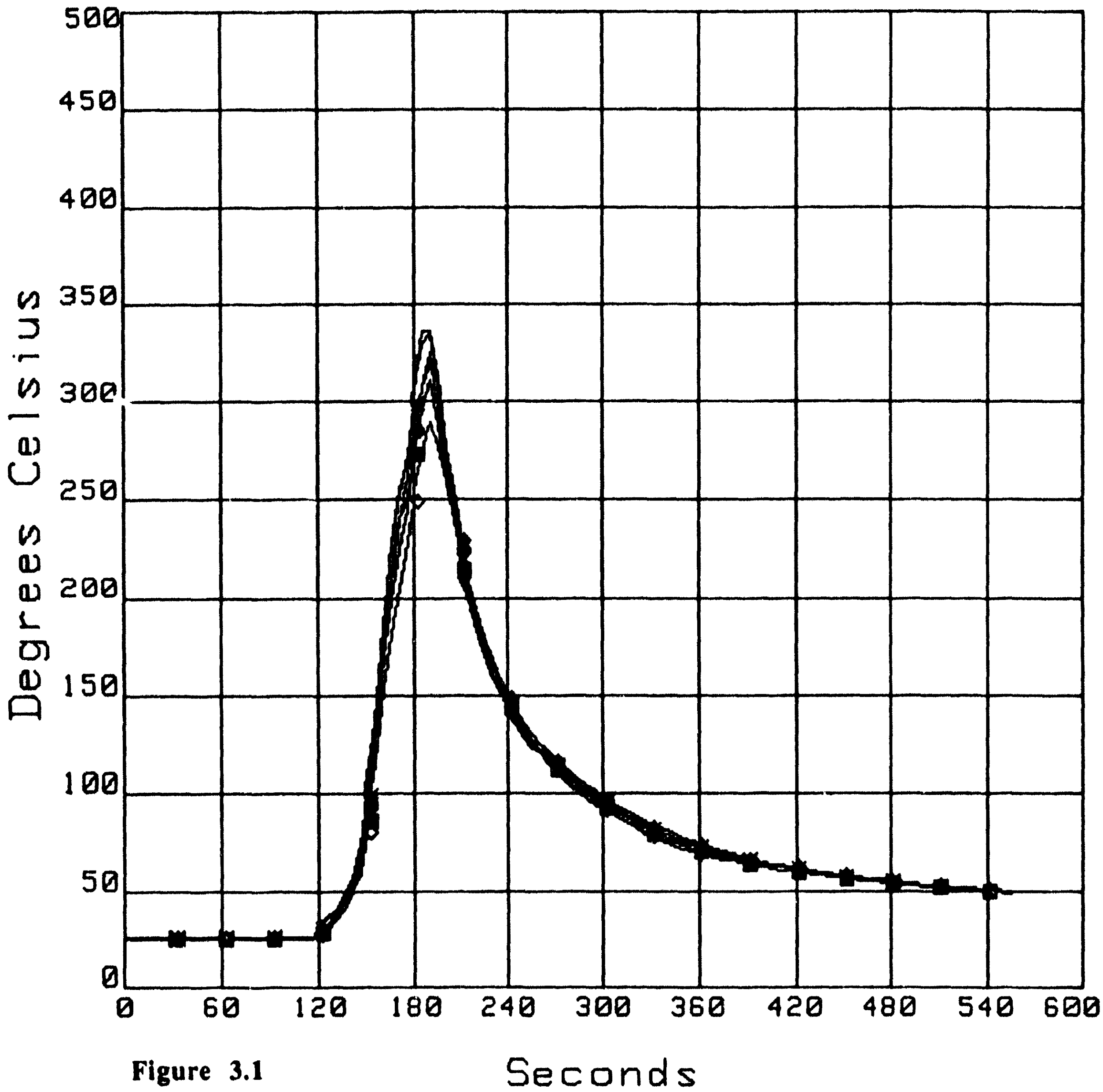


Figure 3.1

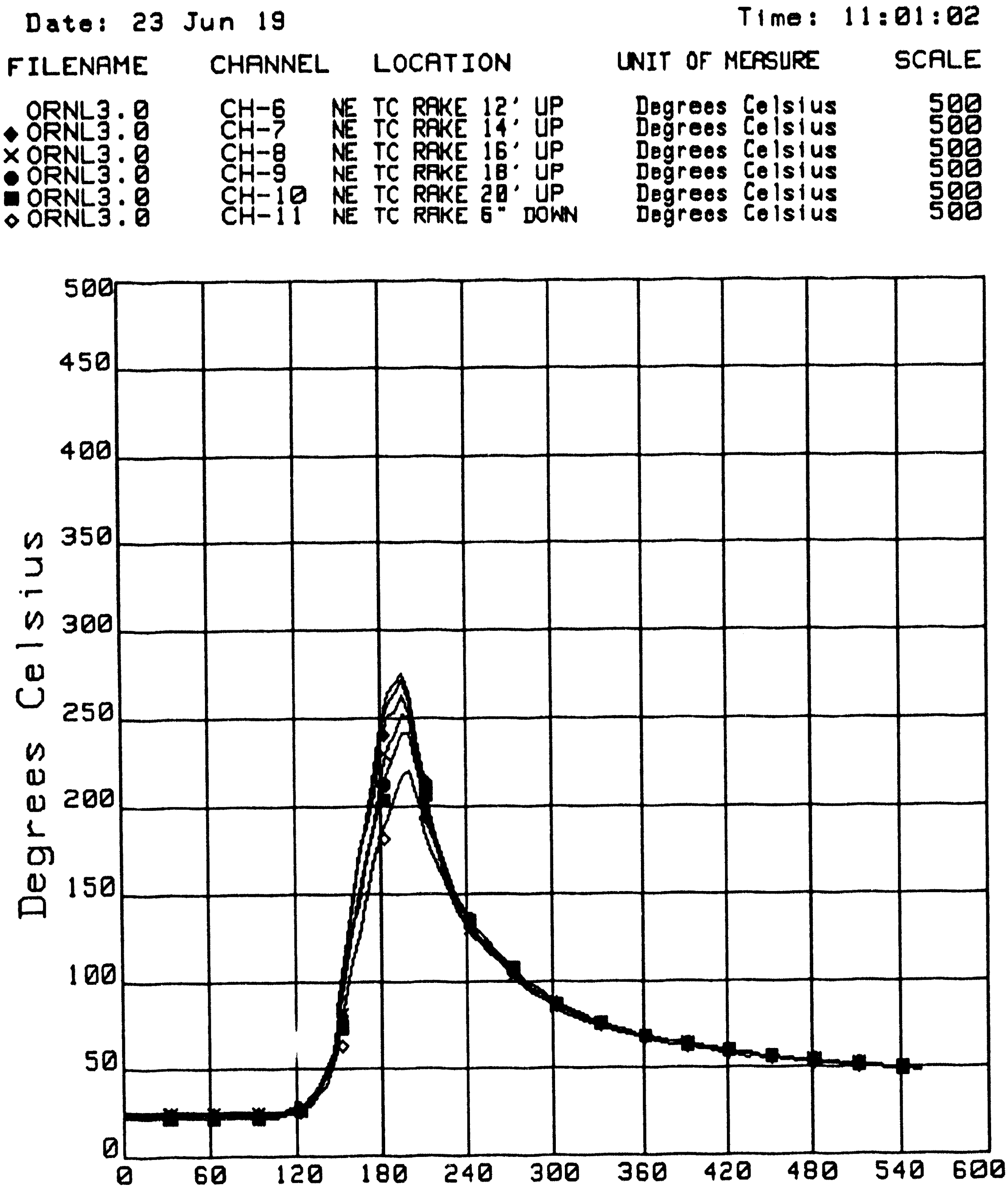

Date: 23 Jun 19
Time: 11:01:02
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL3.0 CH-6 NE TC RAKE 12' UP Degrees Celsius 500
◆ ORNL3.0 CH-7 NE TC RAKE 14' UP Degrees Celsius 500
× ORNL3.0 CH-8 NE TC RAKE 16' UP Degrees Celsius 500
● ORNL3.0 CH-9 NE TC RAKE 18' UP Degrees Celsius 500
■ ORNL3.0 CH-10 NE TC RAKE 20' UP Degrees Celsius 500
◇ ORNL3.0 CH-11 NE TC RAKE 6" DOWN Degrees Celsius 500
Degrees Celsius
0
50
100
150
200
250
300
350
400
450
500
0
60
120
180
240
300
360
420
480
540
600
Seconds

Figure 3.2

Date: 23 Jun 19 Time: 11:01:02

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL3.0	CH-20	So TC RAKE 6" UP	Degrees Celsius	1200
◆ORNL3.0	CH-21	So TC RAKE 2' UP	Degrees Celsius	1200
×ORNL3.0	CH-22	So TC RAKE 4' UP	Degrees Celsius	1200
●ORNL3.0	CH-23	So TC RAKE 6' UP	Degrees Celsius	1200

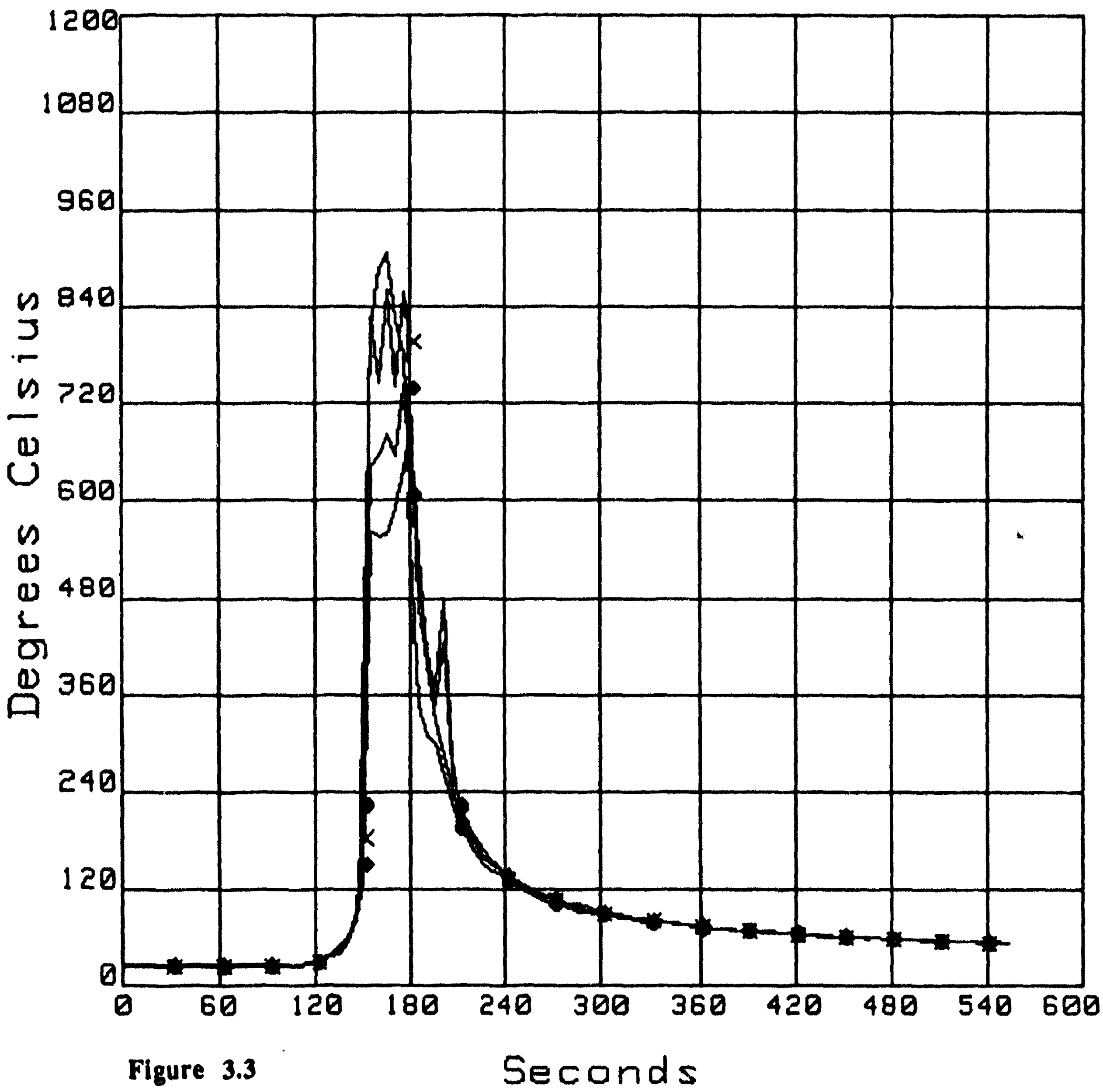


Figure 3.3

Date: 23 Jun 19 Time: 11:01:02

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL3.0	CH-27	TOP So WINDOW TC	Degrees Celsius	500
◆ ORNL3.0	CH-28	TOP No WINDOW TC	Degrees Celsius	500
× ORNL3.0	CH-29	BOTTOM So WINDOW TC	Degrees Celsius	500
● ORNL3.0	CH-30	BOTTOM No WINDOW TC	Degrees Celsius	500

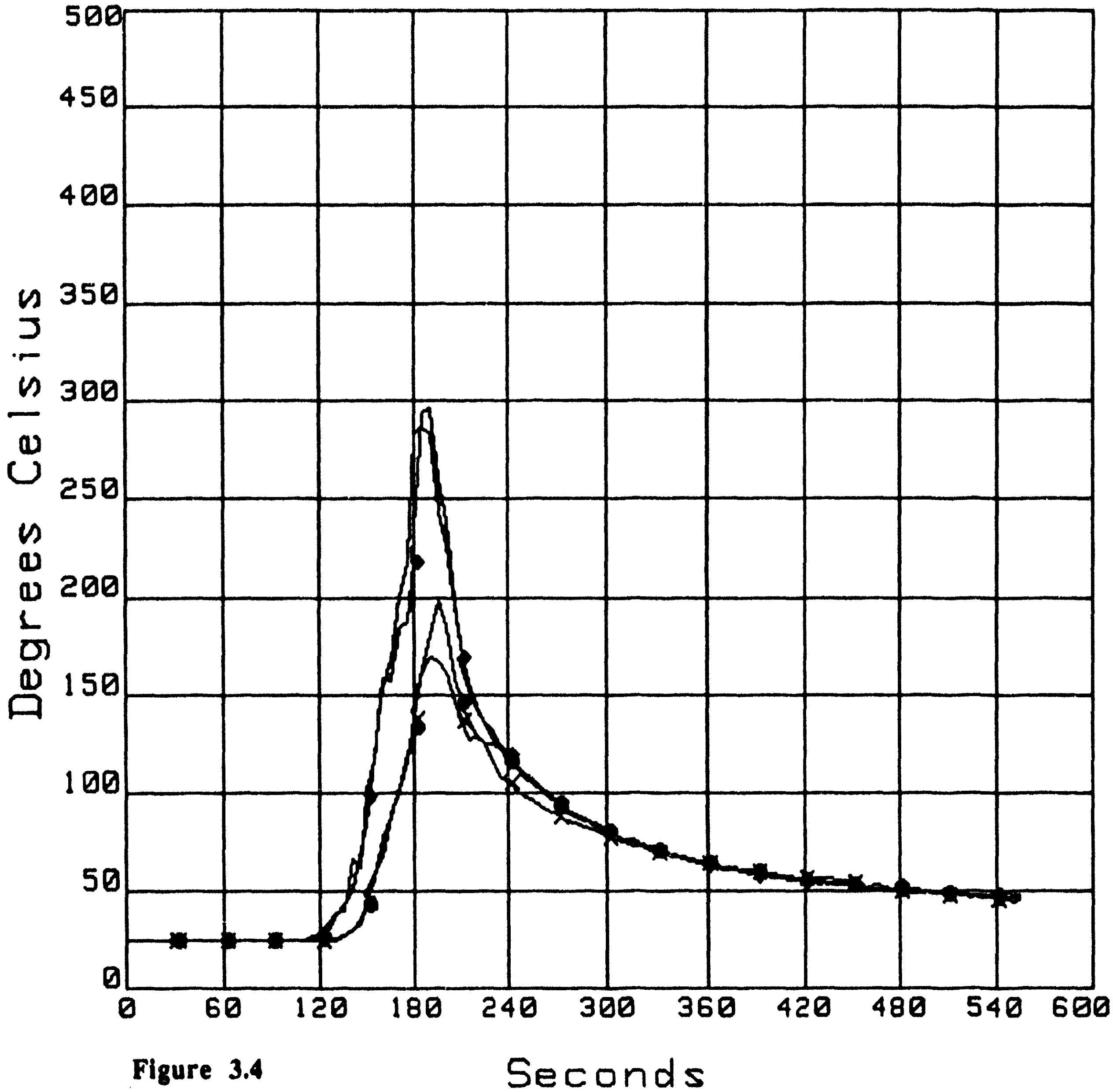


Figure 3.4

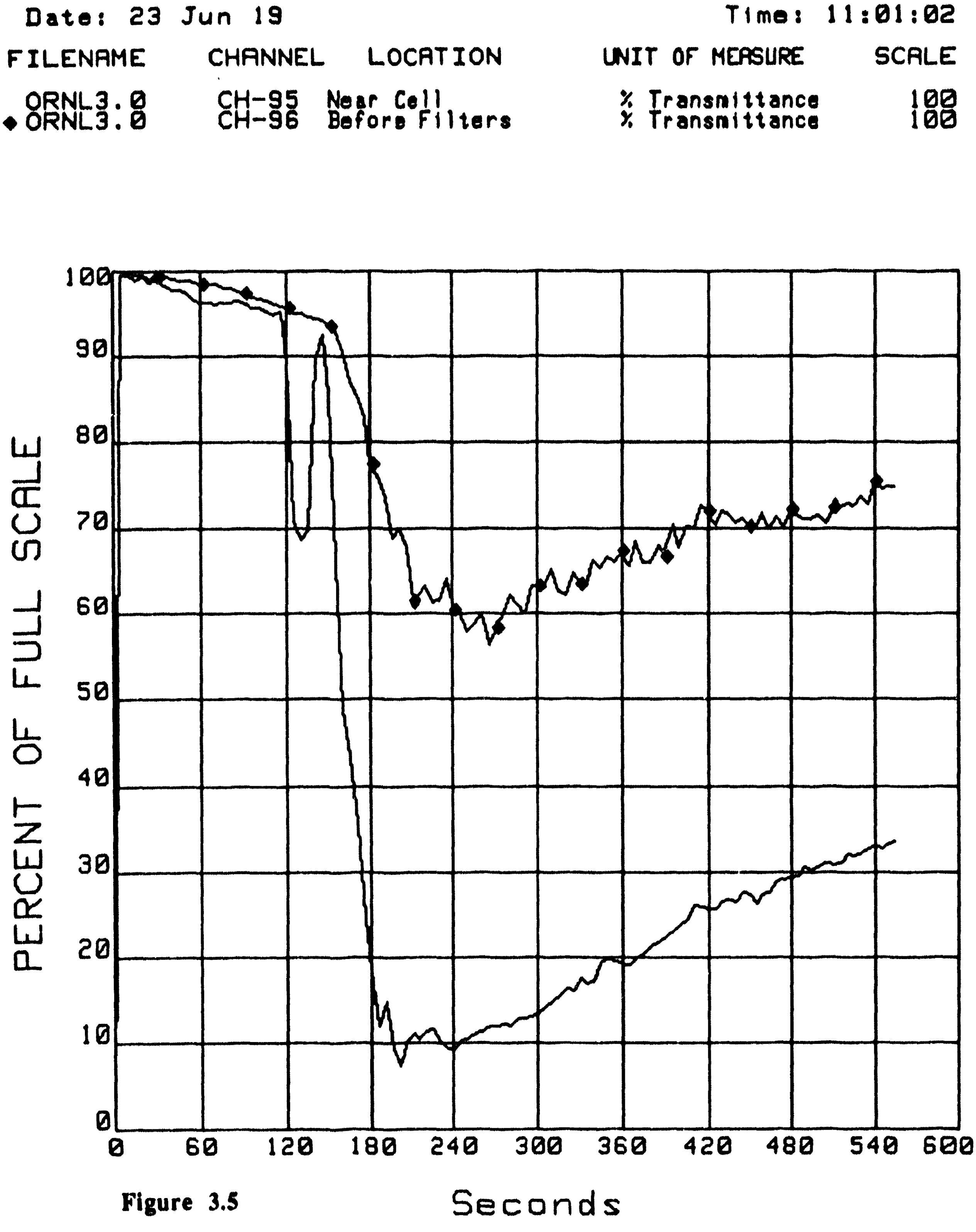

Date: 23 Jun 19
Time: 11:01:02
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL3.0 CH-95 Near Cell % Transmittance 100
◆ ORNL3.0 CH-96 Before Filters % Transmittance 100
PERCENT OF FULL SCALE
0
10
20
30
40
50
60
70
80
90
100
0 60 120 180 240 300 360 420 480 540 600
Seconds

Figure 3.5

Date: 23 Jun 19 Time: 11:01:02

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL3.0	CH-102	Inlet A/F (TFM)	CFM	5000
◆ ORNL3.0	CH-104	Exit A/F (Pitot)	CFM	5000
× ORNL3.0	CH-105	Exit A/F (TFM)	CFM	5000

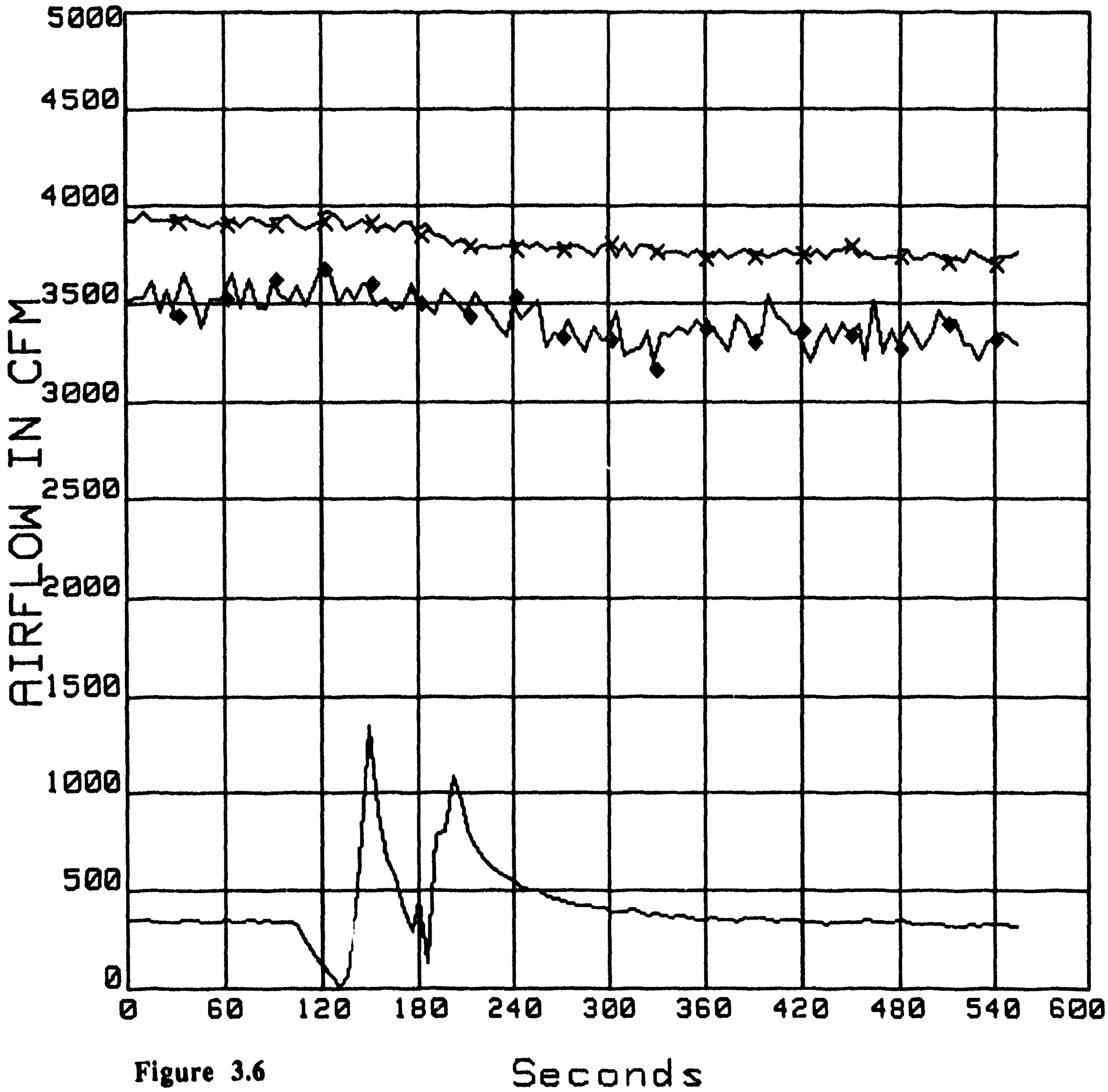
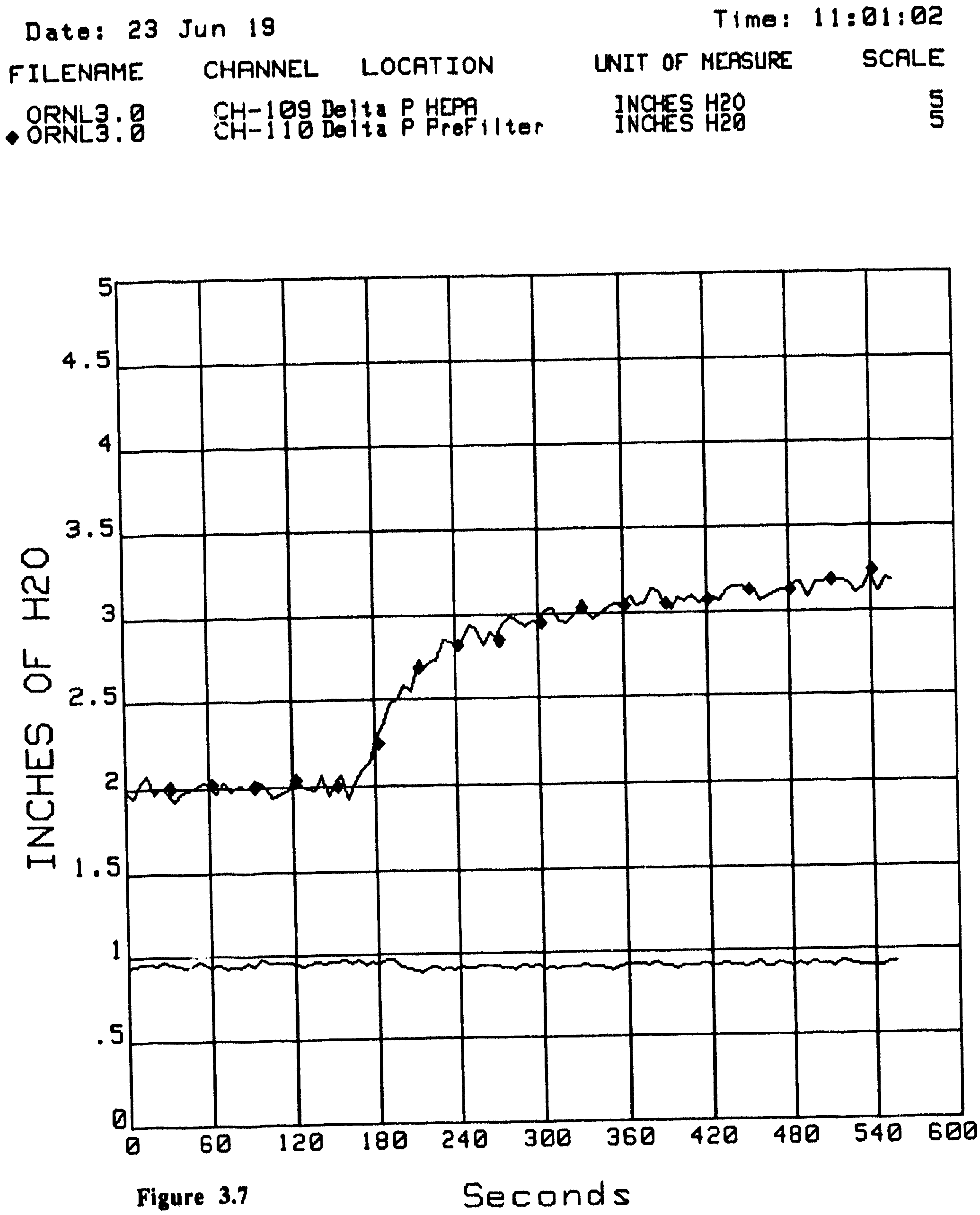
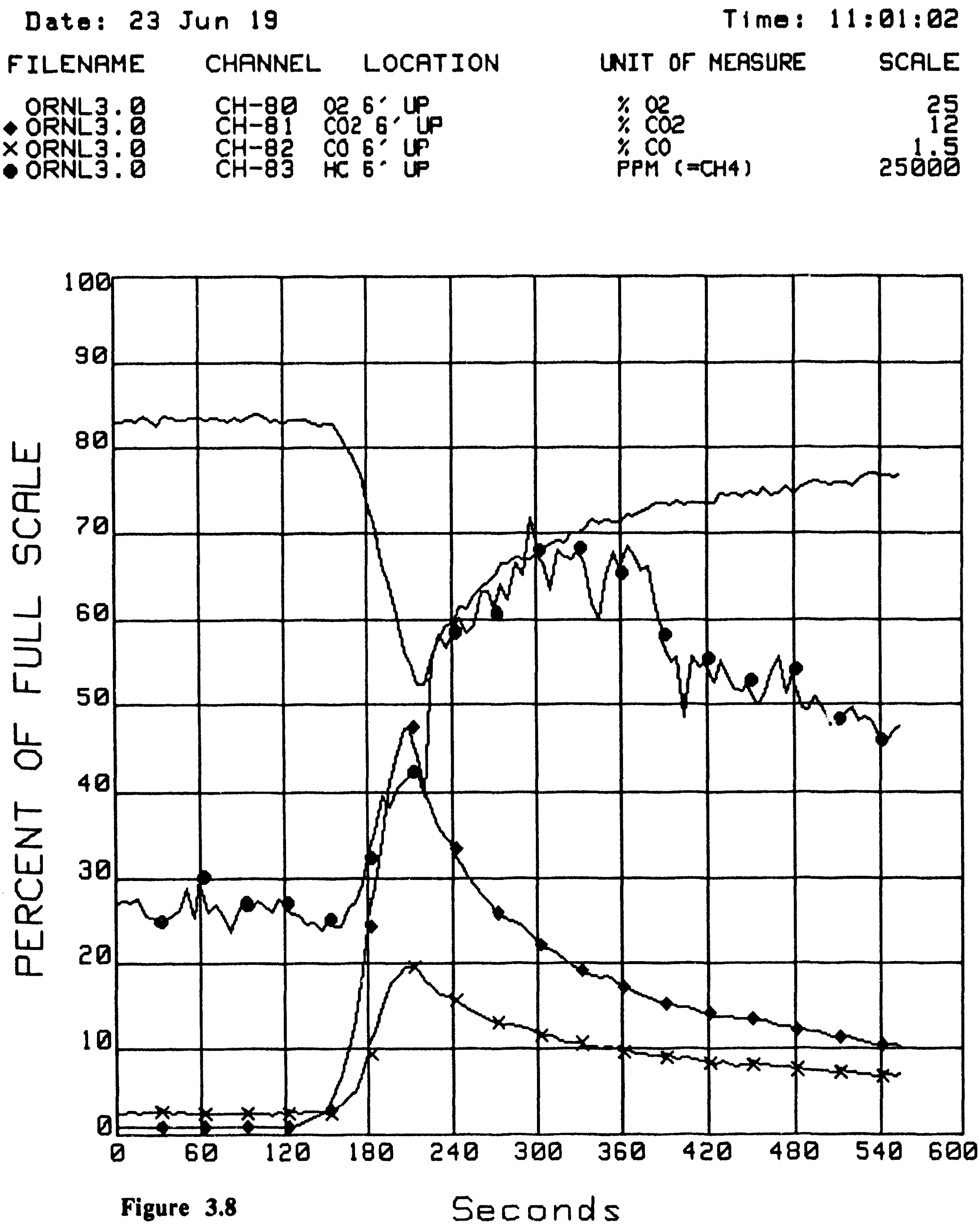


Figure 3.6



Date: 23 Jun 19
Time: 11:01:02
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL3.0 CH-109 Delta P HEPA INCHES H20 5
◆ ORNL3.0 CH-110 Delta P PreFilter INCHES H20 5
INCHES OF H20
5
4.5
4
3.5
3
2.5
2
1.5
1
.5
0
0 60 120 180 240 300 360 420 480 540 600
Seconds

Figure 3.7



Date: 23 Jun 19
Time: 11:01:02
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL3.0 CH-80 O2 6´ UP % O2 25
◆ ORNL3.0 CH-81 CO2 6´ UP % CO2 12
× ORNL3.0 CH-82 CO 6´ UP % CO 1.5
● ORNL3.0 CH-83 HC 6´ UP PPM (=CH4) 25000
PERCENT OF FULL SCALE
0
10
20
30
40
50
60
70
80
90
100
0 60 120 180 240 300 360 420 480 540 600
Seconds

Figure 3.8

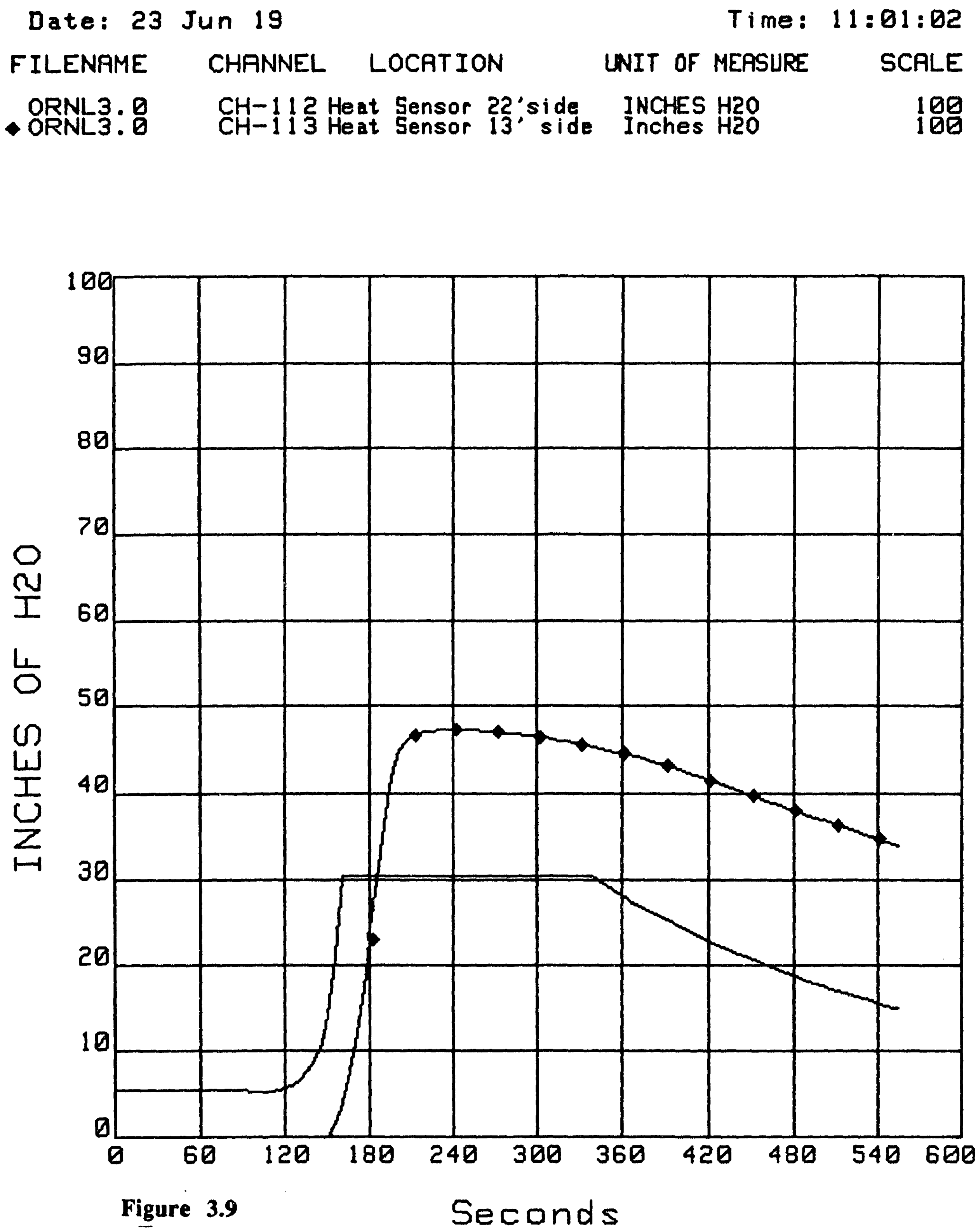

Date: 23 Jun 19
Time: 11:01:02
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL3.0 CH-112 Heat Sensor 22'side INCHES H2O 100
◆ ORNL3.0 CH-113 Heat Sensor 13' side Inches H2O 100
INCHES OF H2O
100
90
80
70
60
50
40
30
20
10
0
0 60 120 180 240 300 360 420 480 540 600
Seconds

Figure 3.9

Date: 23 Jun 19 Time: 11:01:02

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL3.0	CH-32	CELL MANIFOLD TC	Degrees Celsius	300
◆ ORNL3.0	CH-34	CEL EXH DUCT TC	Degrees Celsius	300
× ORNL3.0	CH-35	EXH/MAKEUP NODE TC	Degrees Celsius	300
● ORNL3.0	CH-36	TC BEFORE PREFILTER	Degrees Celsius	300
■ ORNL3.0	CH-37	TC BEFORE HEPA	Degrees Celsius	300

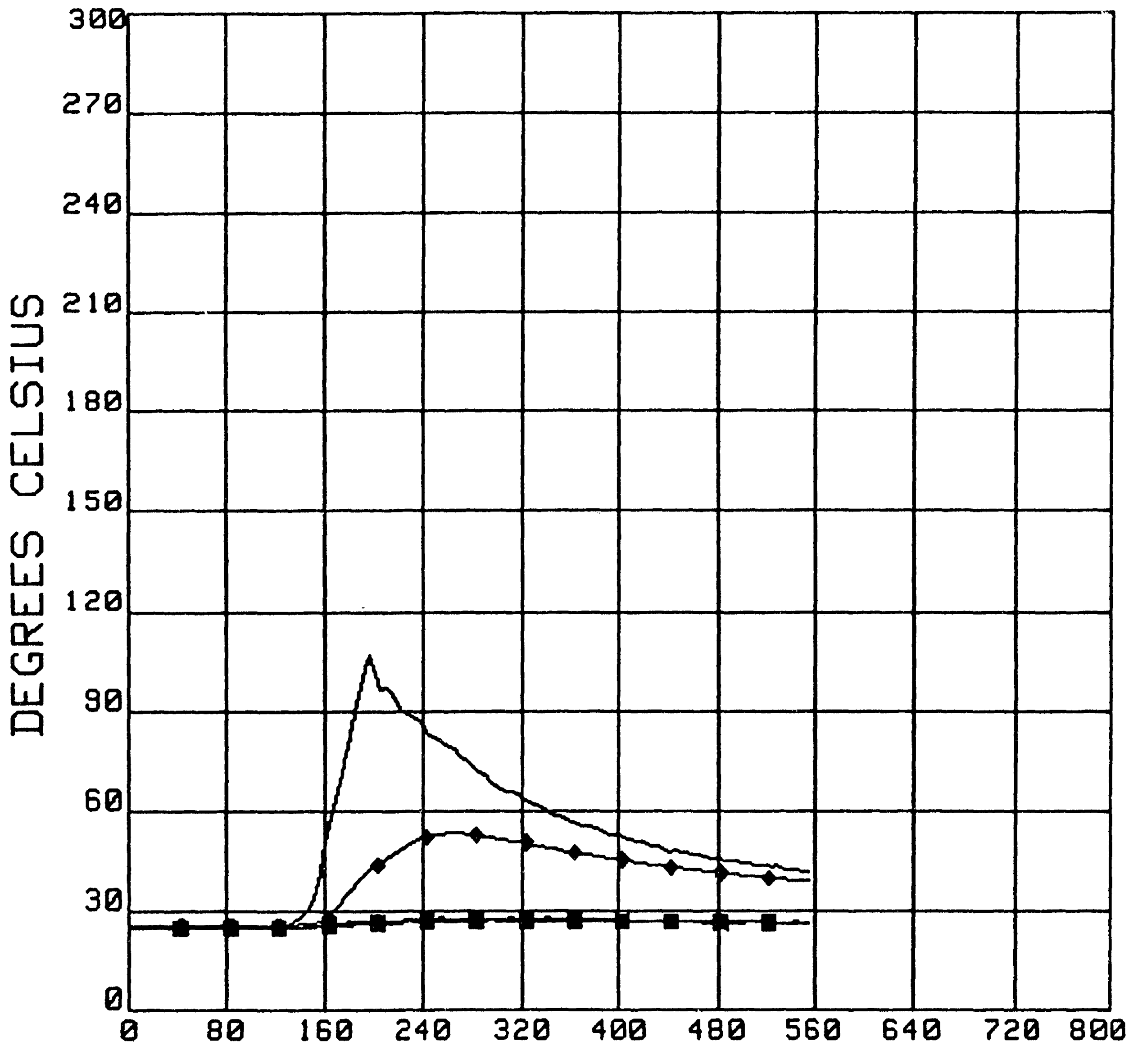


Figure 3.10

Date: 23 Jun 19 Time: 11:01:02

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL3.0	CH-84	O2 12' UP	% O2	25
◆ ORNL3.0	CH-85	CO2 12' UP	% CO2	12
× ORNL3.0	CH-86	CO 12' UP	% CO	1.5
● ORNL3.0	CH-87	HC 12'UP	PPM (=CH4)	25000

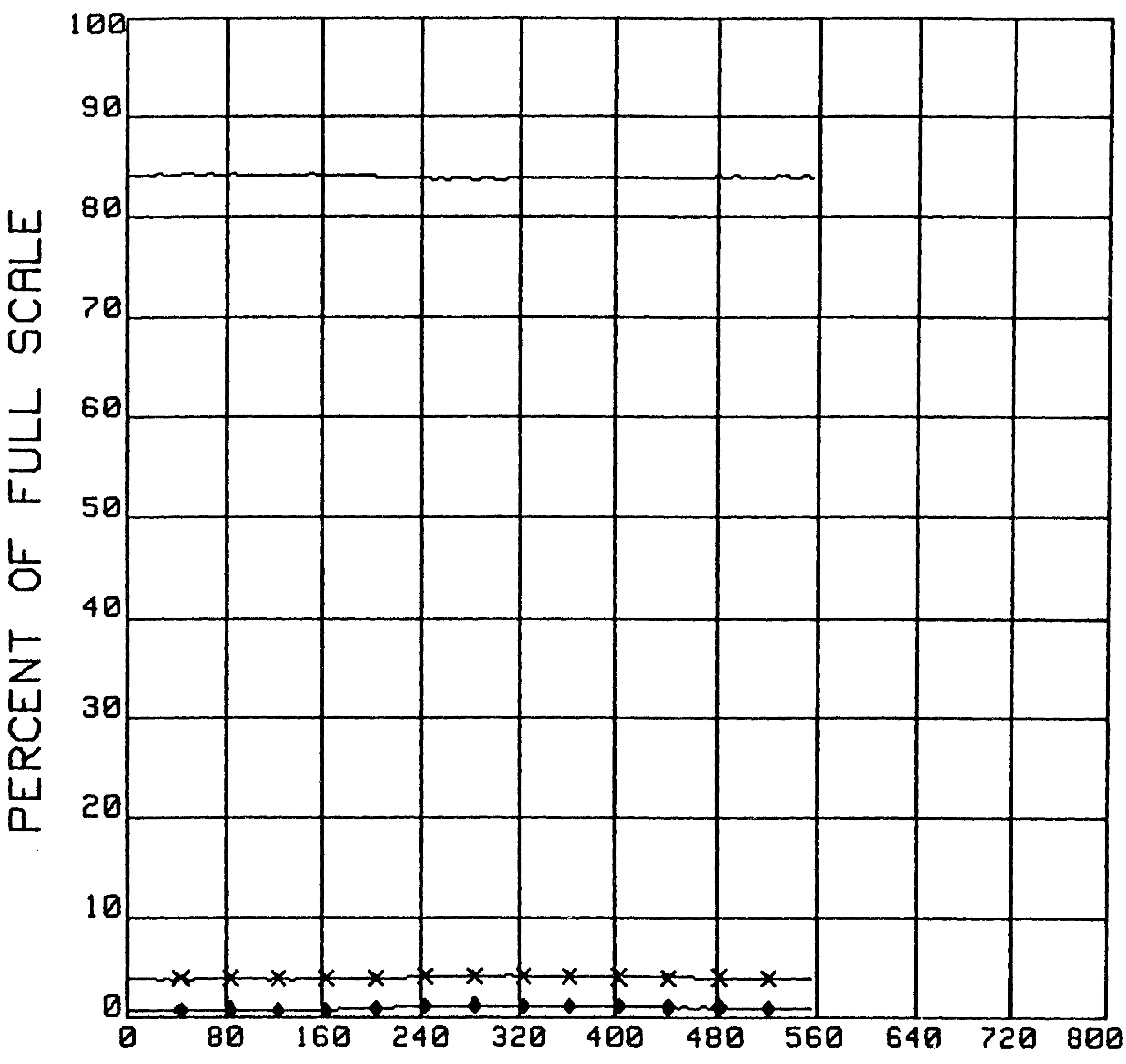


Figure 3.11

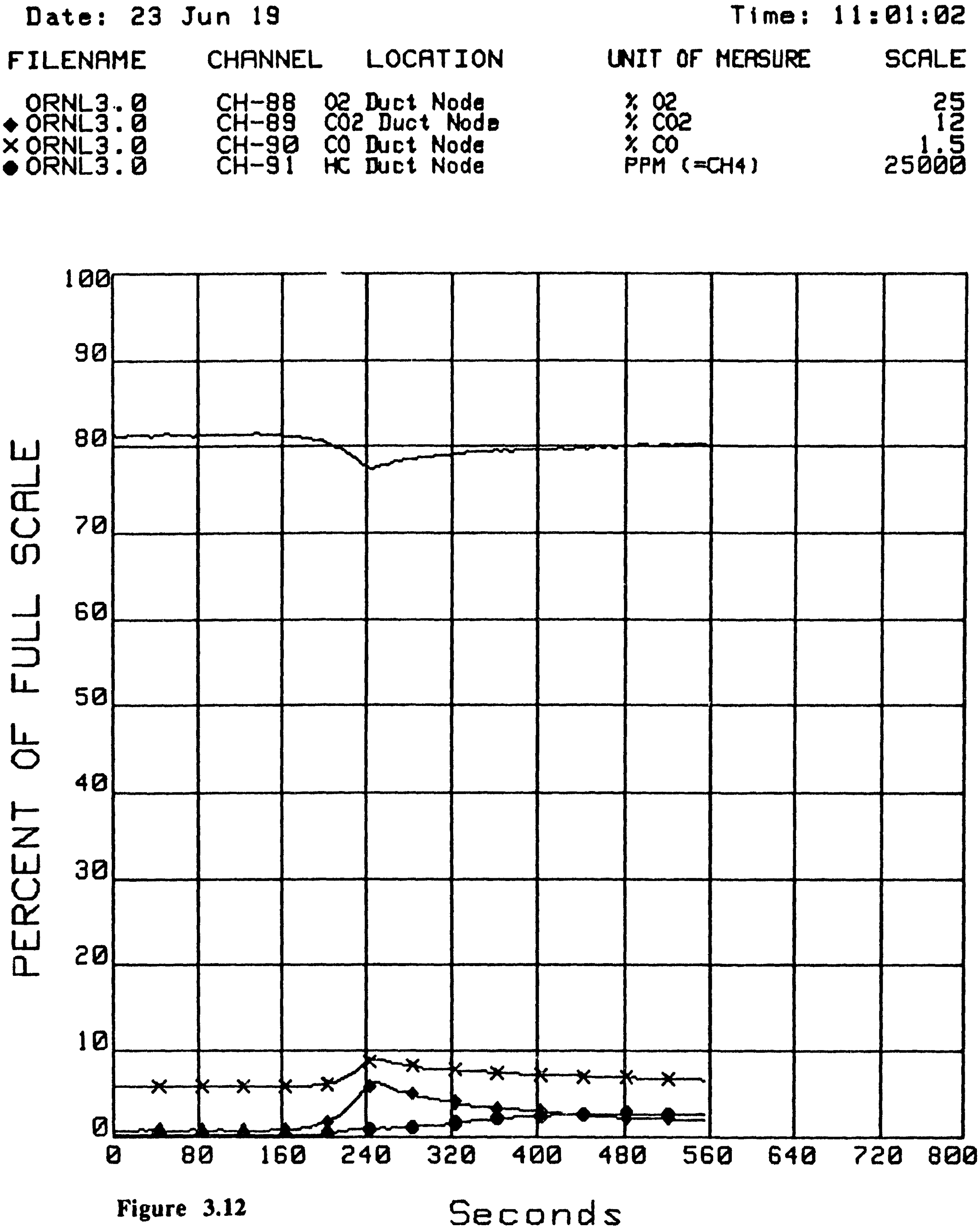

Date: 23 Jun 19
Time: 11:01:02
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL3.0 CH-88 O2 Duct Node % O2 25
ORNL3.0 CH-89 CO2 Duct Node % CO2 12
ORNL3.0 CH-90 CO Duct Node % CO 1.5
ORNL3.0 CH-91 HC Duct Node PPM (=CH4) 25000
PERCENT OF FULL SCALE
0 10 20 30 40 50 60 70 80 90 100
0 80 160 240 320 400 480 560 640 720 800
Seconds

Figure 3.12

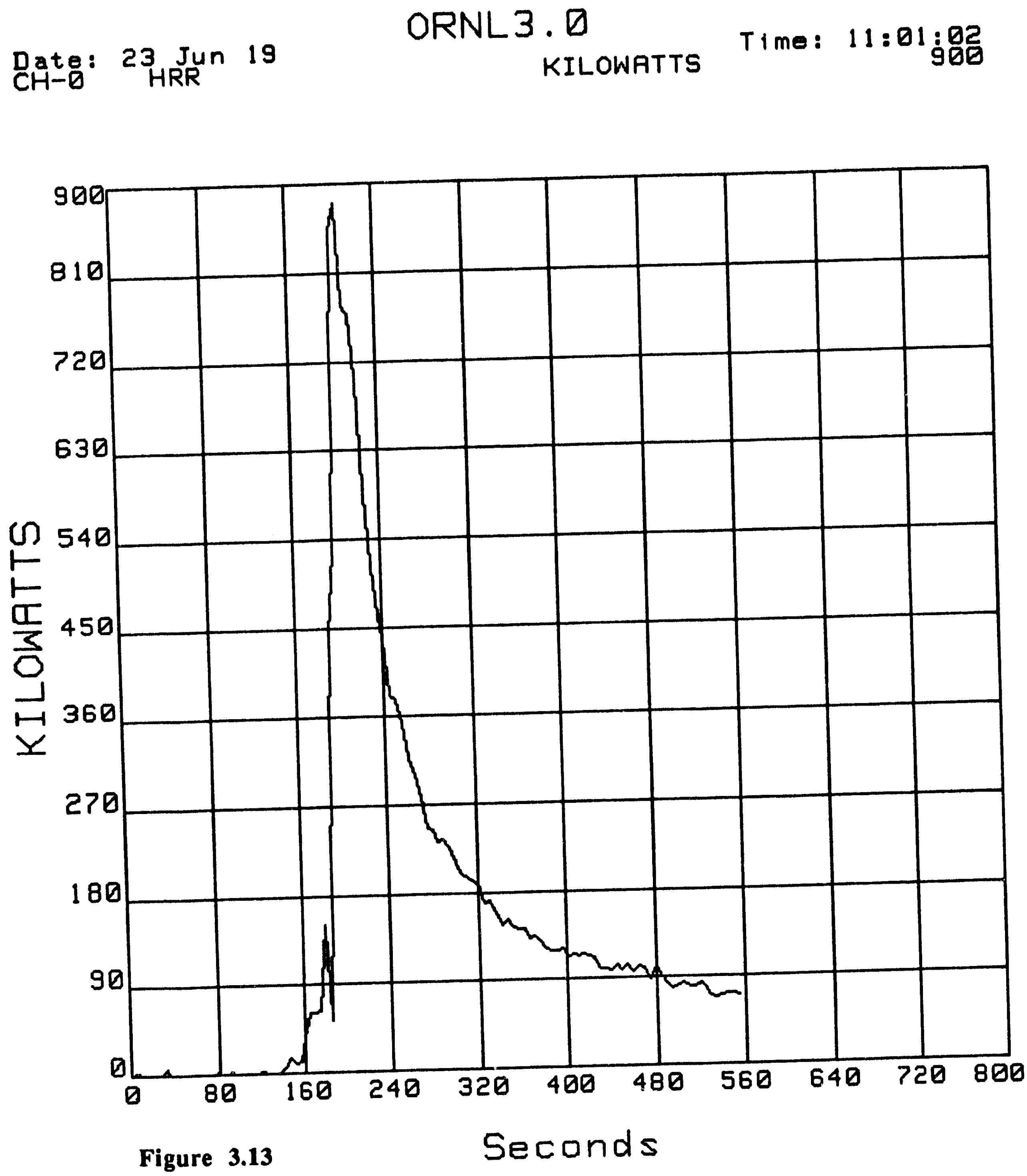
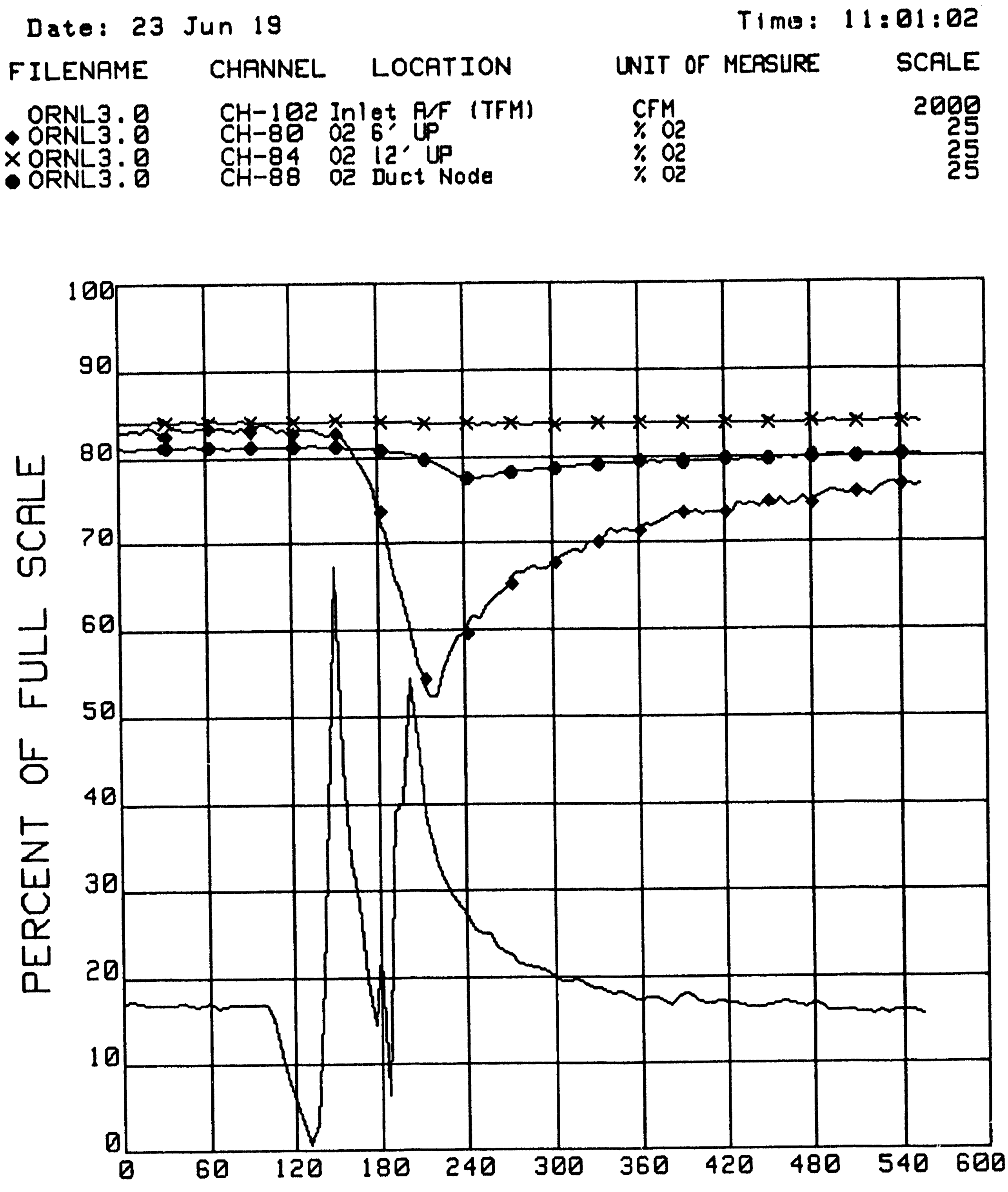


Figure 3.13

No. of channels=73



Date: 23 Jun 19
Time: 11:01:02
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL3.0 CH-102 Inlet A/F (TFM) CFM 2000
◆ ORNL3.0 CH-80 O2 6' UP % O2 25
× ORNL3.0 CH-84 O2 12' UP % O2 25
● ORNL3.0 CH-88 O2 Duct Node % O2 25
PERCENT OF FULL SCALE
100
90
80
70
60
50
40
30
20
10
0
0 60 120 180 240 300 360 420 480 540 600
Seconds

Figure 3.14

Date: 7 Jul 19 Time: 14:02:20

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL4.0	CH-0	NE TC RAKE 6" UP	Degrees Celsius	500
◆ ORNL4.0	CH-1	NE TC RAKE 2´ UP	Degrees Celsius	500
× ORNL4.0	CH-2	NE TC RAKE 4´ UP	Degrees Celsius	500
● ORNL4.0	CH-3	NE TC RAKE 6´ UP	Degrees Celsius	500
■ ORNL4.0	CH-4	NE TC RAKE 8´ UP	Degrees Celsius	500
◇ ORNL4.0	CH-5	NE TC RAKE 10´ UP	Degrees Celsius	500

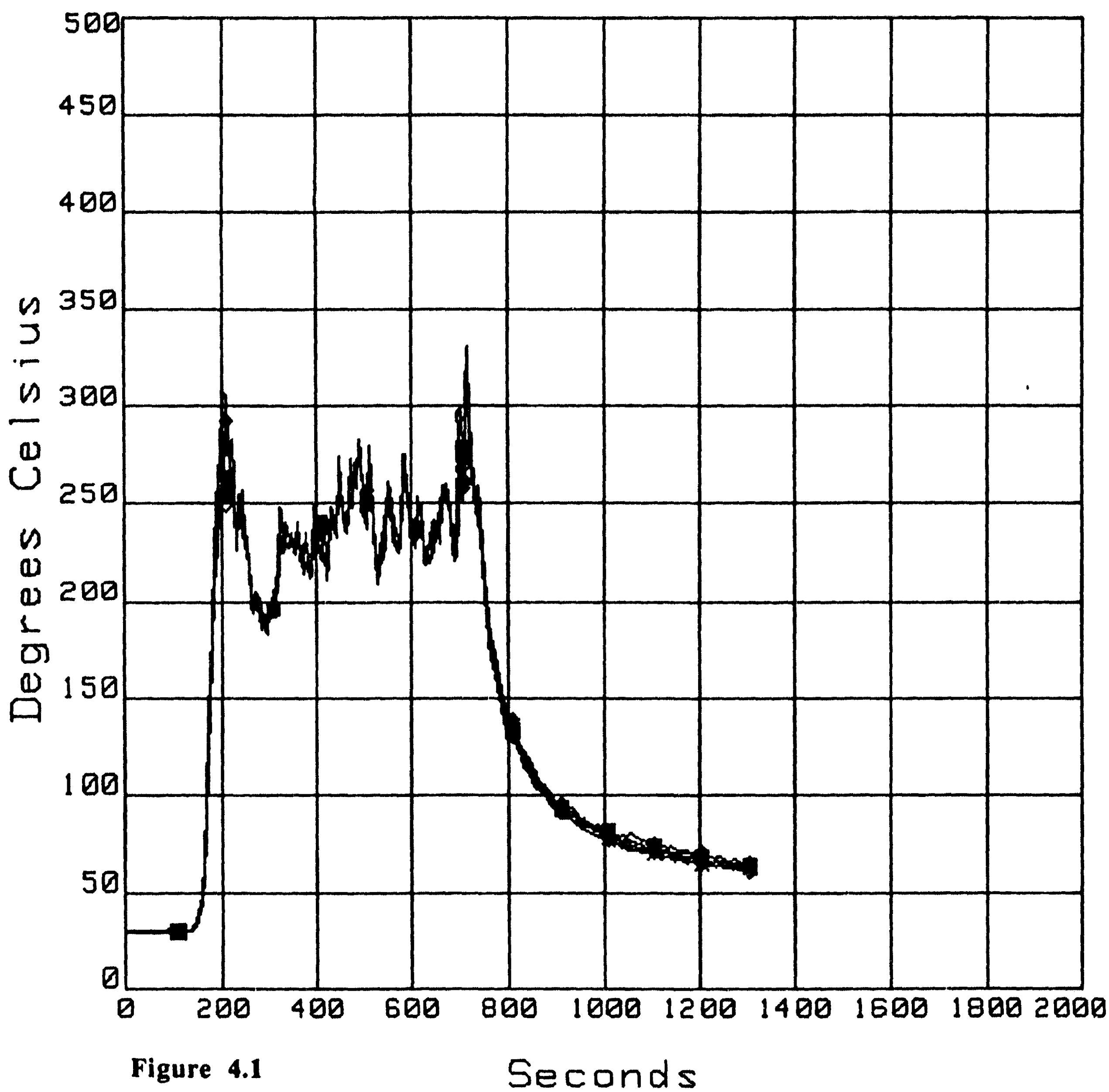


Figure 4.1

Date: 7 Jul 19 Time: 14:02:20

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL4.0	CH-6	NE TC RAKE 12' UP	Degrees Celsius	500
◆ ORNL4.0	CH-7	NE TC RAKE 14' UP	Degrees Celsius	500
× ORNL4.0	CH-8	NE TC RAKE 16' UP	Degrees Celsius	500
● ORNL4.0	CH-9	NE TC RAKE 18' UP	Degrees Celsius	500
■ ORNL4.0	CH-10	NE TC RAKE 20' UP	Degrees Celsius	500
◇ ORNL4.0	CH-11	NE TC RAKE 6" DOWN	Degrees Celsius	500

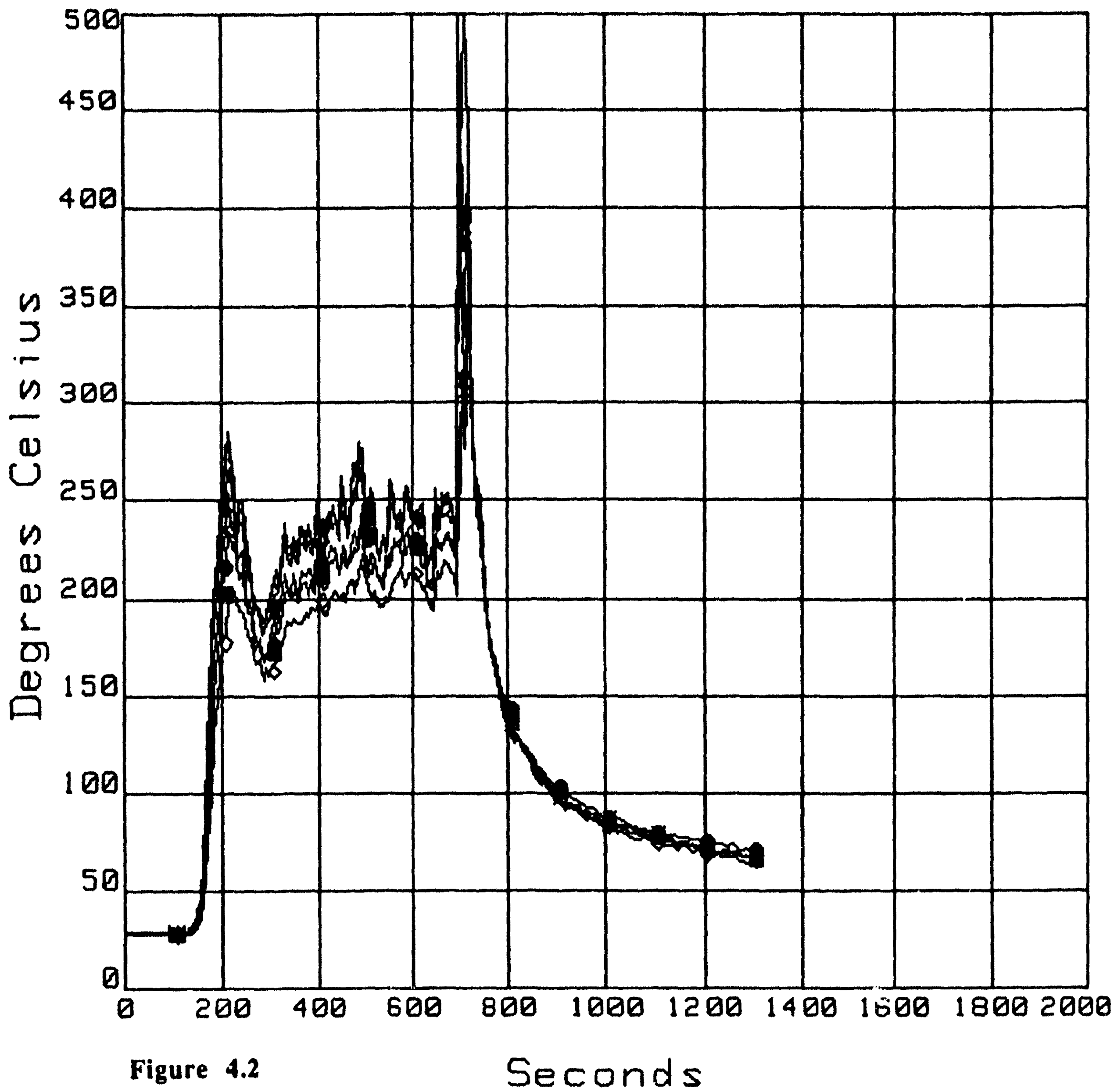


Figure 4.2

Date: 7 Jul 19 Time: 14:02:20

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL4.0	CH-20	So TC RAKE 6" UP	Degrees Celsius	1200
◆ ORNL4.0	CH-21	So TC RAKE 2' UP	Degrees Celsius	1200
× ORNL4.0	CH-22	So TC RAKE 4' UP	Degrees Celsius	1200
● ORNL4.0	CH-23	So TC RAKE 6' UP	Degrees Celsius	1200

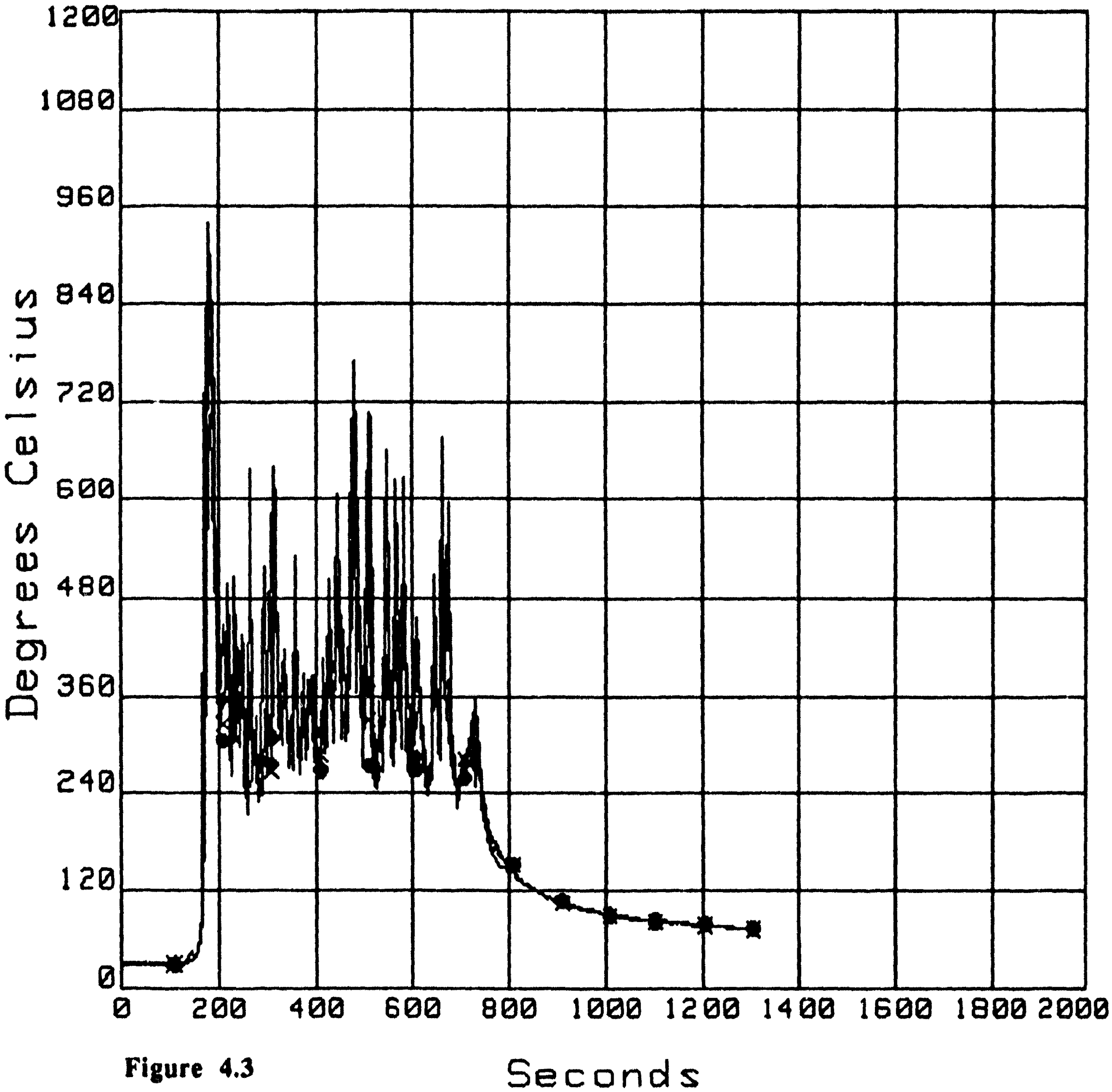


Figure 4.3

Date: 7 Jul 19 Time: 14:02:20

	FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
	ORNL4.0	CH-27	TOP So WINDOW TC	Degrees Celsius	500
◆	ORNL4.0	CH-28	TOP No WINDOW TC	Degrees Celsius	500
×	ORNL4.0	CH-29	BOTTOM So WINDOW TC	Degrees Celsius	500
●	ORNL4.0	CH-30	BOTTOM No WINDOW TC	Degrees Celsius	500

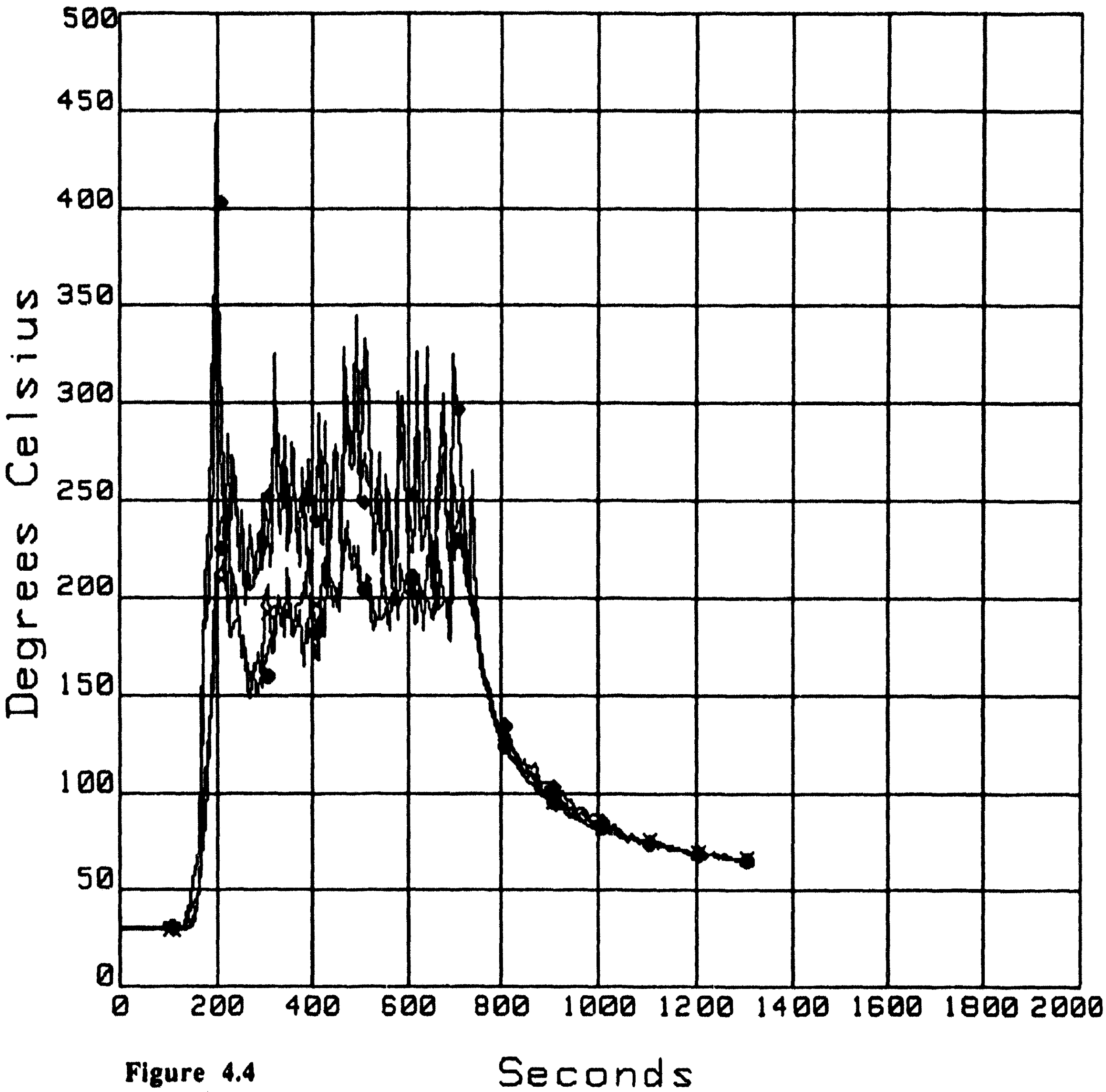


Figure 4.4

Date: 7 Jul 19 Time: 14:02:20

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL4.0	CH-80	O2 6' UP	% O2	25
◆ ORNL4.0	CH-81	CO2 6' UP	% CO2	12
× ORNL4.0	CH-82	CO 6' UP	% CO	1.5
● ORNL4.0	CH-83	HC 6' UP	PPM (=CH4)	25000

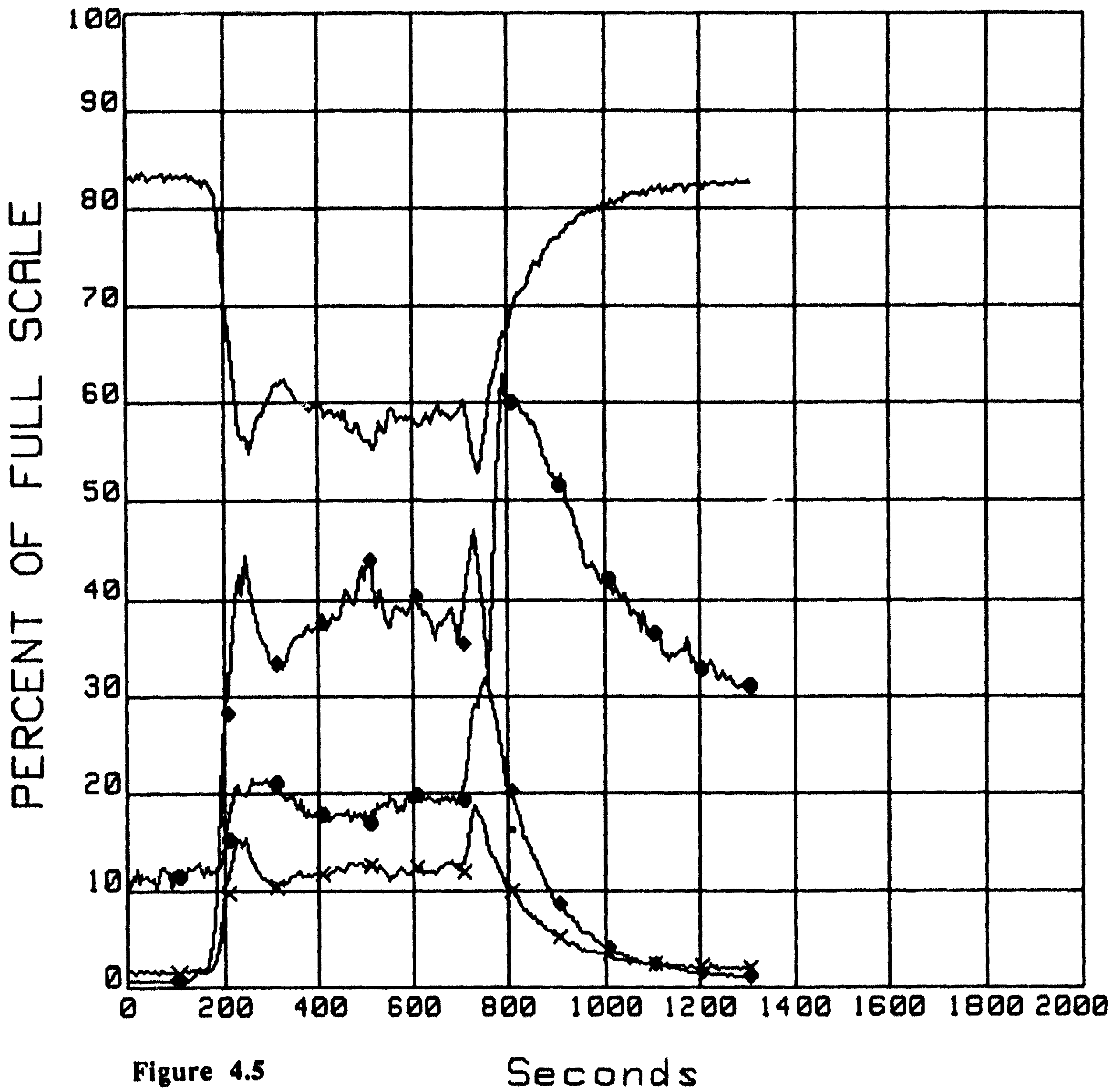


Figure 4.5

Date: 7 Jul 19 Time: 14:02:20

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL4.0	CH-95	Near Cell	% Transmittance	100
◆ ORNL4.0	CH-96	Before Filters	% Transmittance	100

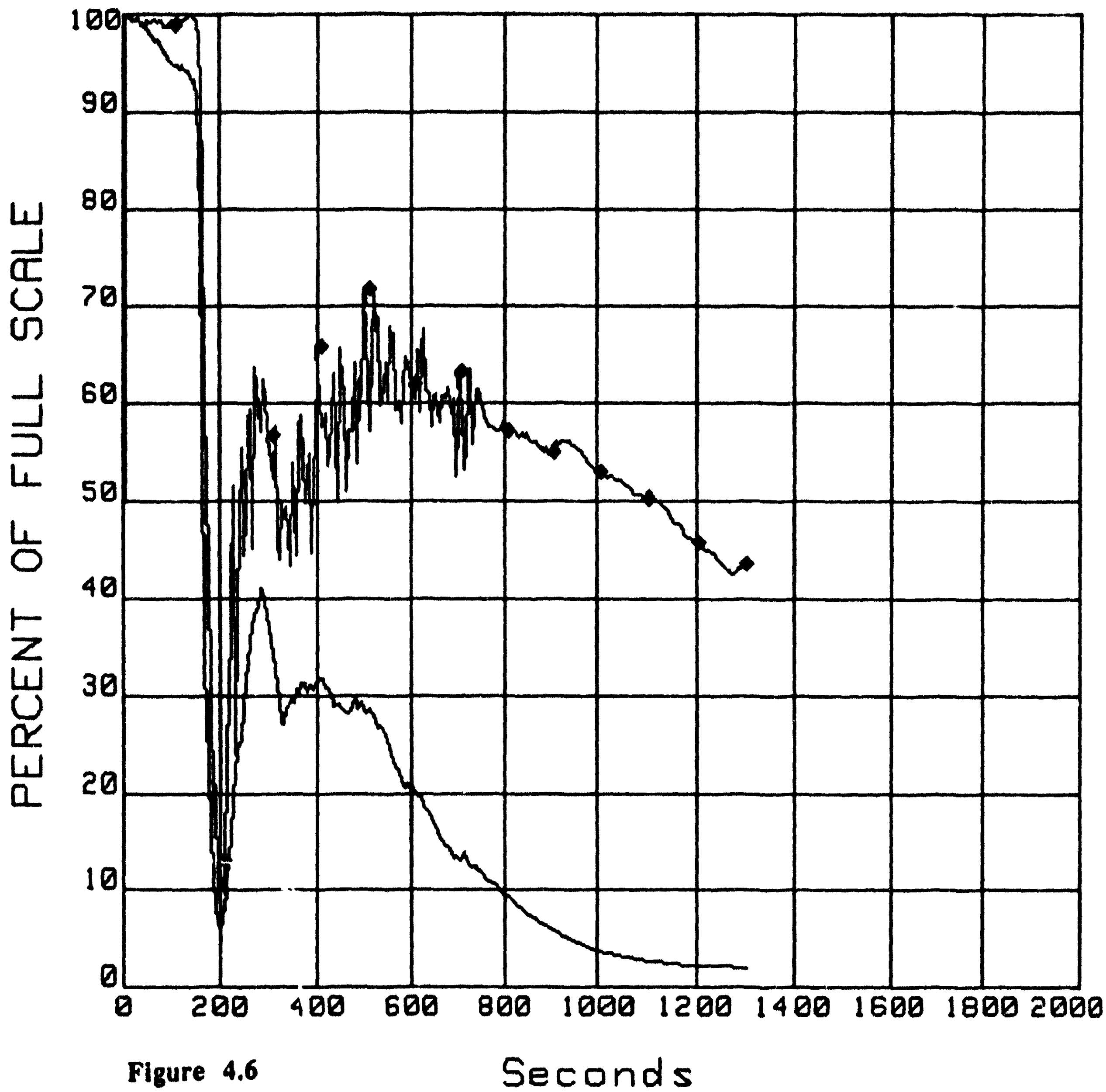
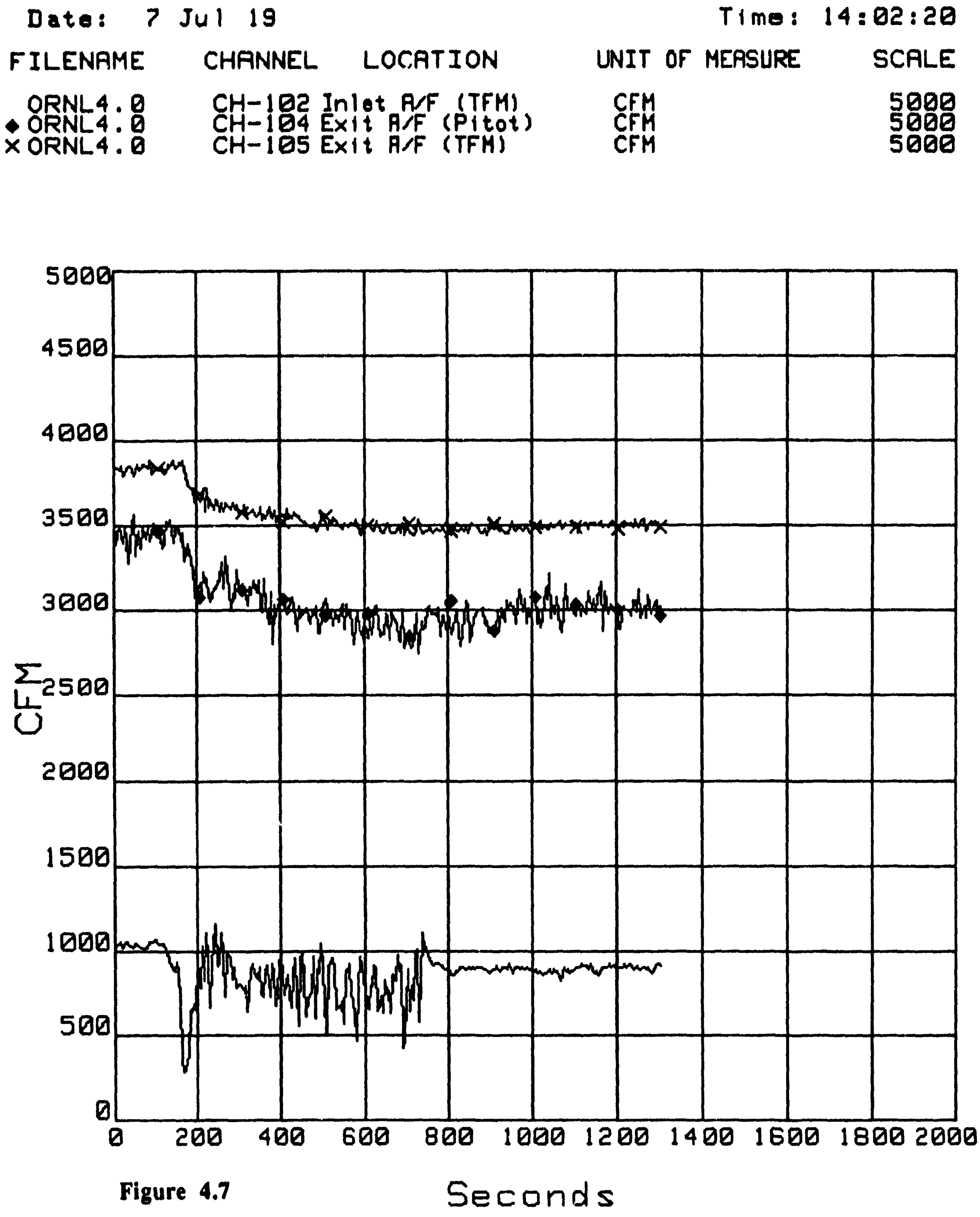


Figure 4.6



Date: 7 Jul 19
Time: 14:02:20
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL4.0 CH-102 Inlet A/F (TFM) CFM 5000
◆ ORNL4.0 CH-104 Exit A/F (Pitot) CFM 5000
× ORNL4.0 CH-105 Exit A/F (TFM) CFM 5000
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
CFM
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Seconds

Figure 4.7

Date: 7 Jul 19 Time: 14:02:20

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL4.0	CH-109	Delta P HEPA	INCHES H20	5
◆ ORNL4.0	CH-110	Delta P PreFilter	INCHES H20	5

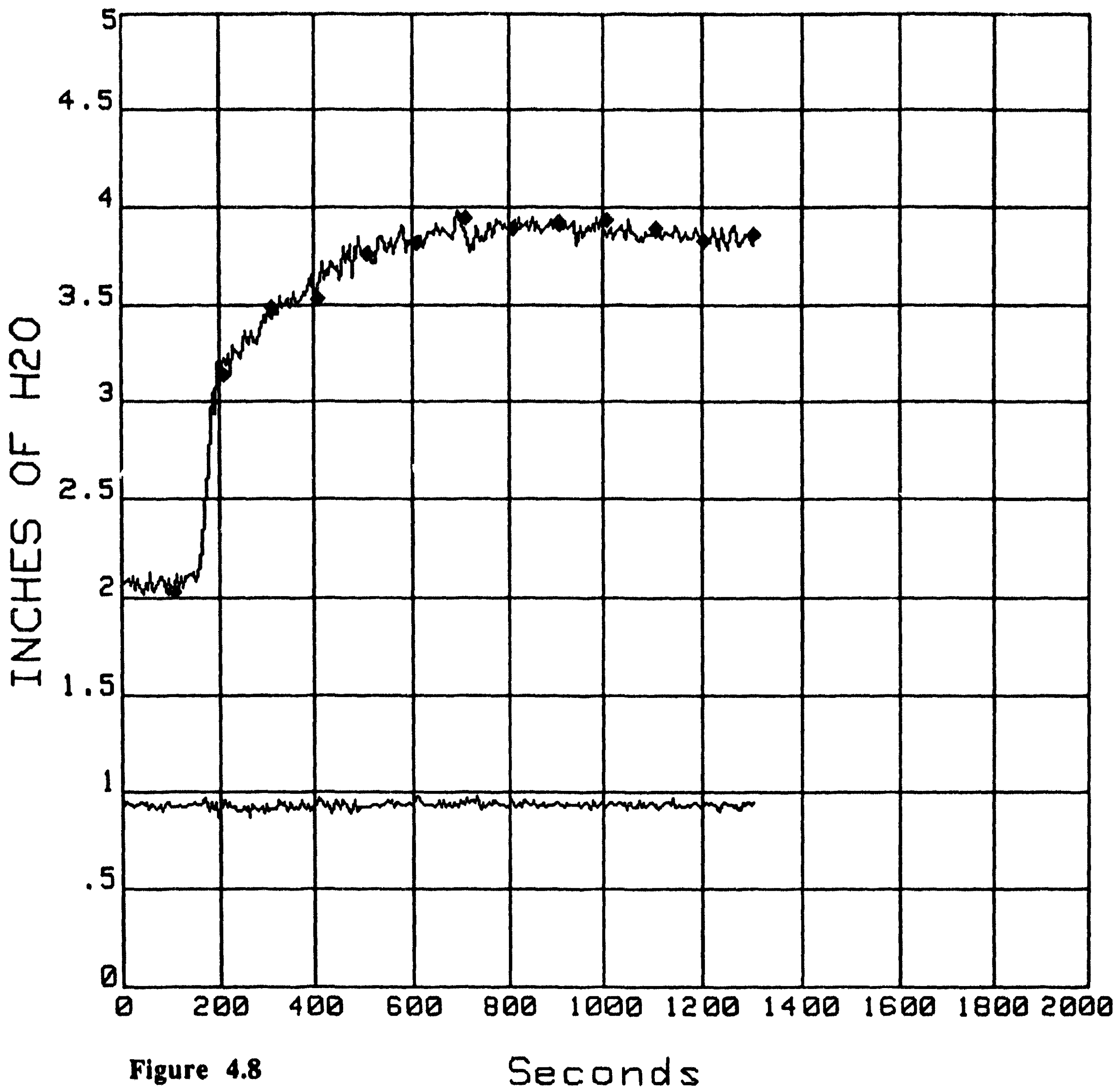


Figure 4.8

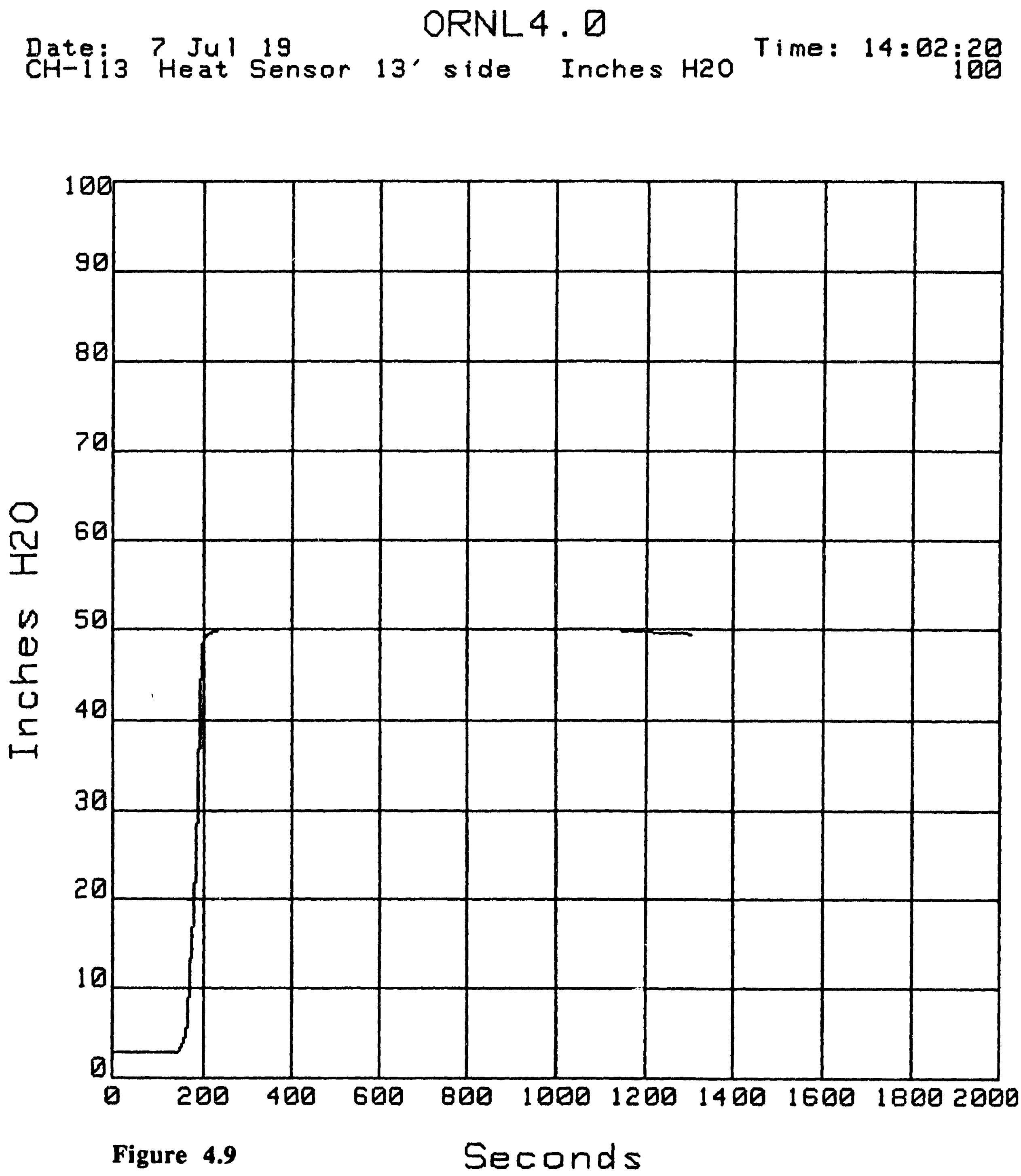


Figure 4.9

No. of channels=73

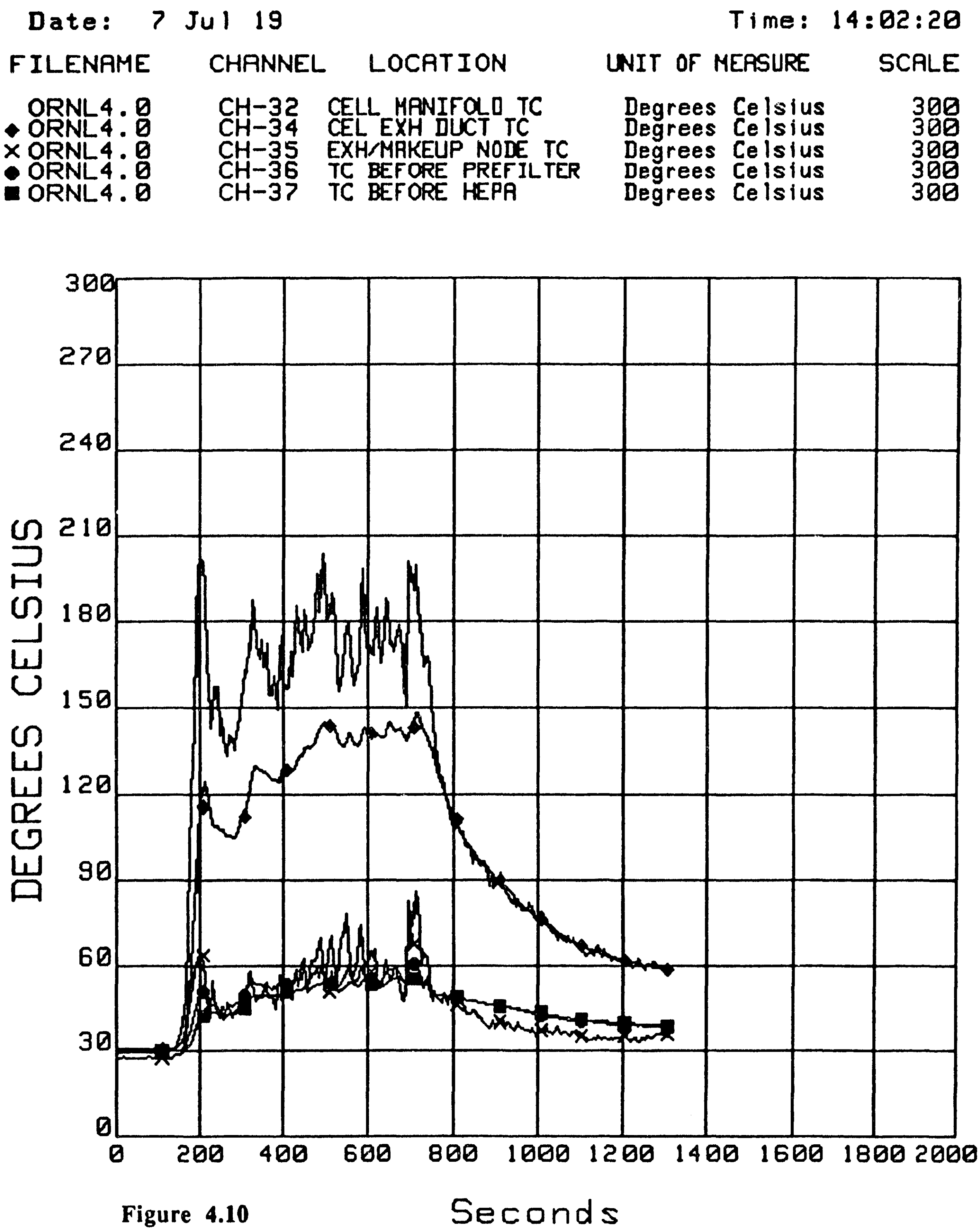

Date: 7 Jul 19
Time: 14:02:20
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL4.0 CH-32 CELL MANIFOLD TC Degrees Celsius 300
ORNL4.0 CH-34 CEL EXH DUCT TC Degrees Celsius 300
ORNL4.0 CH-35 EXH/MAKEUP NODE TC Degrees Celsius 300
ORNL4.0 CH-36 TC BEFORE PREFILTER Degrees Celsius 300
ORNL4.0 CH-37 TC BEFORE HEPA Degrees Celsius 300
DEGREES CELSIUS
0
30
60
90
120
150
180
210
240
270
300
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Seconds

Figure 4.10

Date: 7 Jul 19 Time: 14:02:20

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL4.0	CH-84	O2 12' UP	% O2	25
◆ ORNL4.0	CH-85	CO2 12' UP	% CO2	12
× ORNL4.0	CH-86	CO 12' UP	% CO	1.5
● ORNL4.0	CH-87	HC 12'UP	PPM (=CH4)	25000

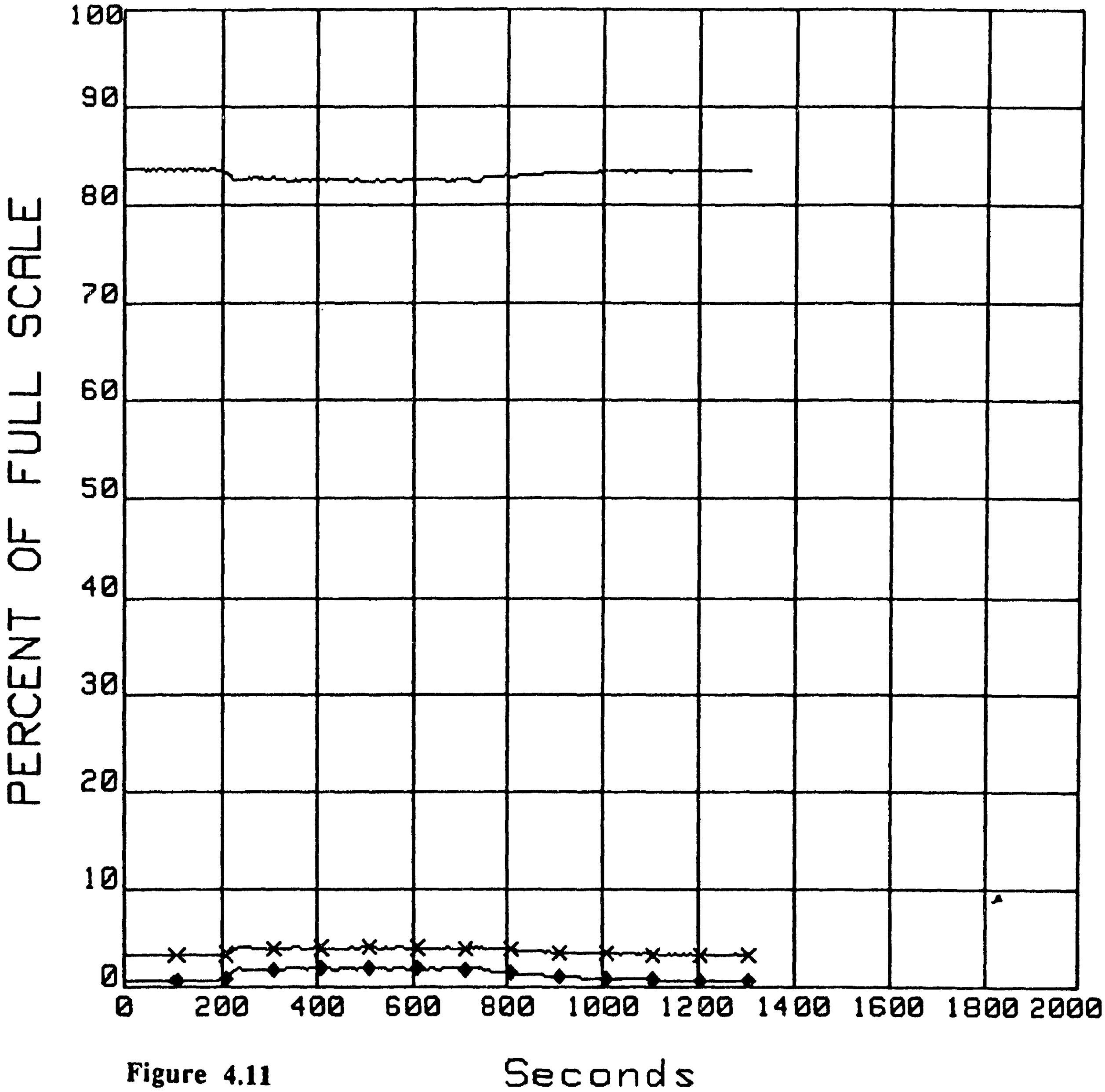


Figure 4.11

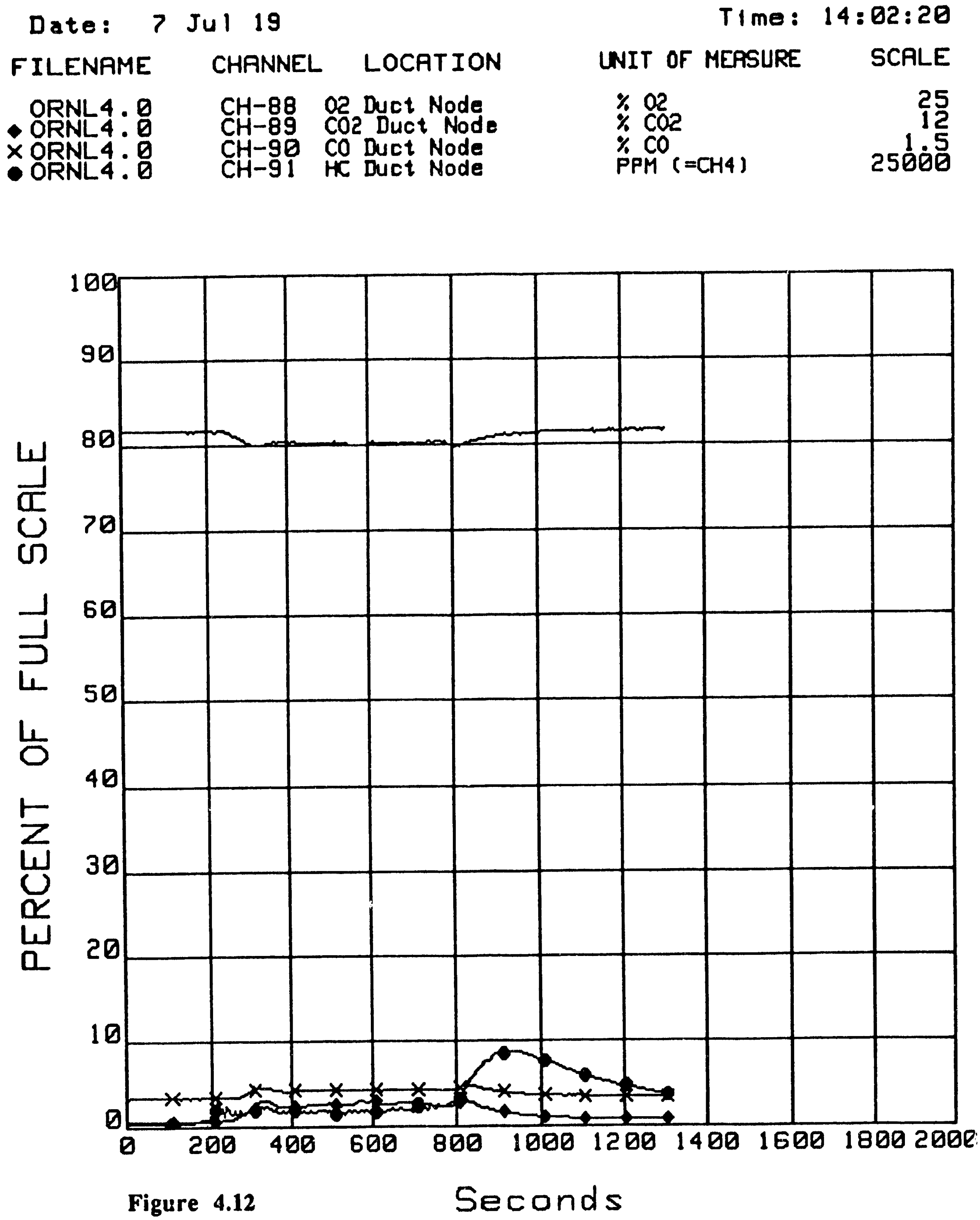

Date: 7 Jul 19
Time: 14:02:20
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL4.0 CH-88 O2 Duct Node % O2 25
◆ ORNL4.0 CH-89 CO2 Duct Node % CO2 12
× ORNL4.0 CH-90 CO Duct Node % CO 1.5
● ORNL4.0 CH-91 HC Duct Node PPM (=CH4) 25000
PERCENT OF FULL SCALE
0 10 20 30 40 50 60 70 80 90 100
0 200 400 600 800 1000 1200 1400 1600 1800 2000
Seconds

Figure 4.12

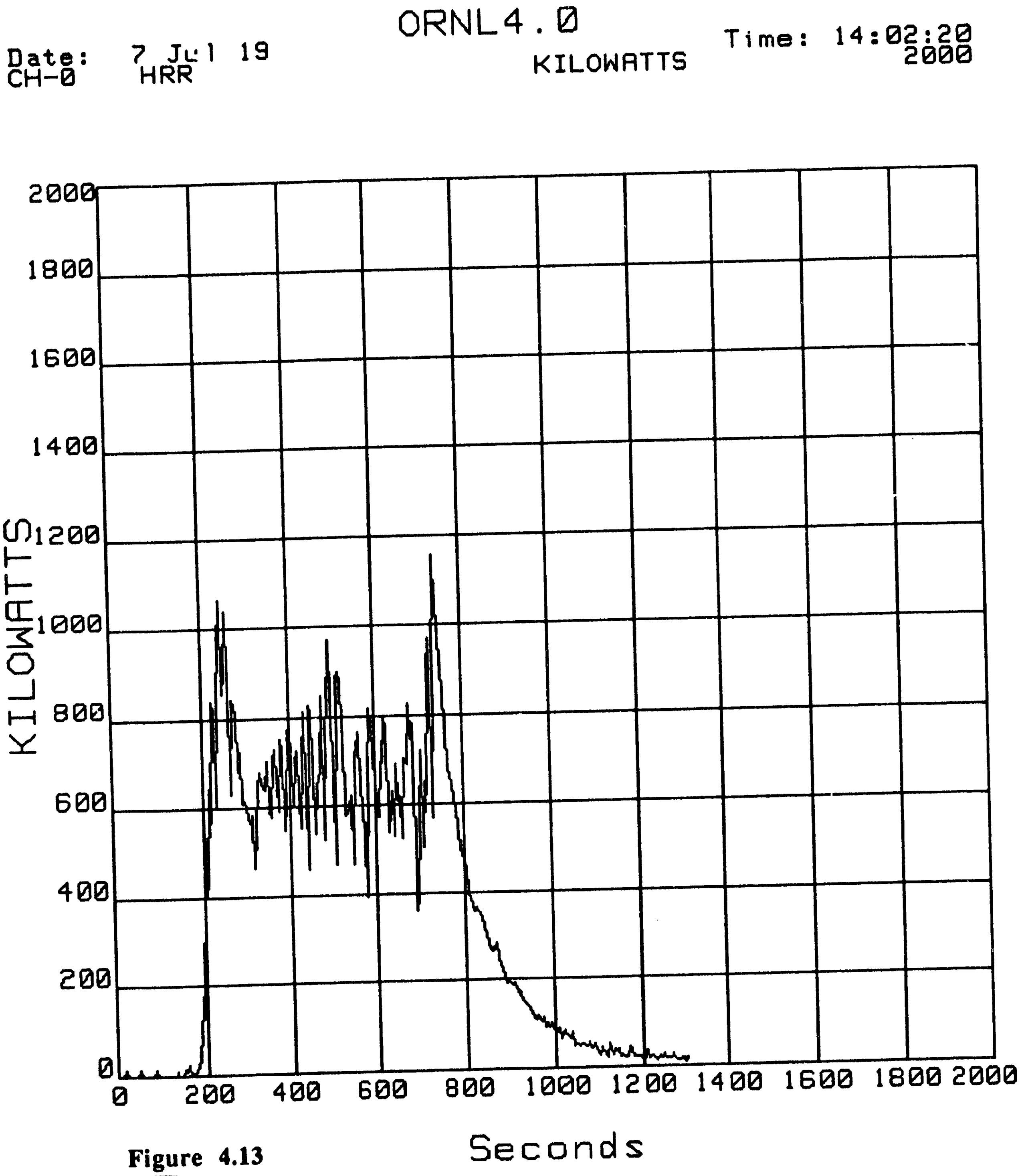


Figure 4.13

No. of channels=73

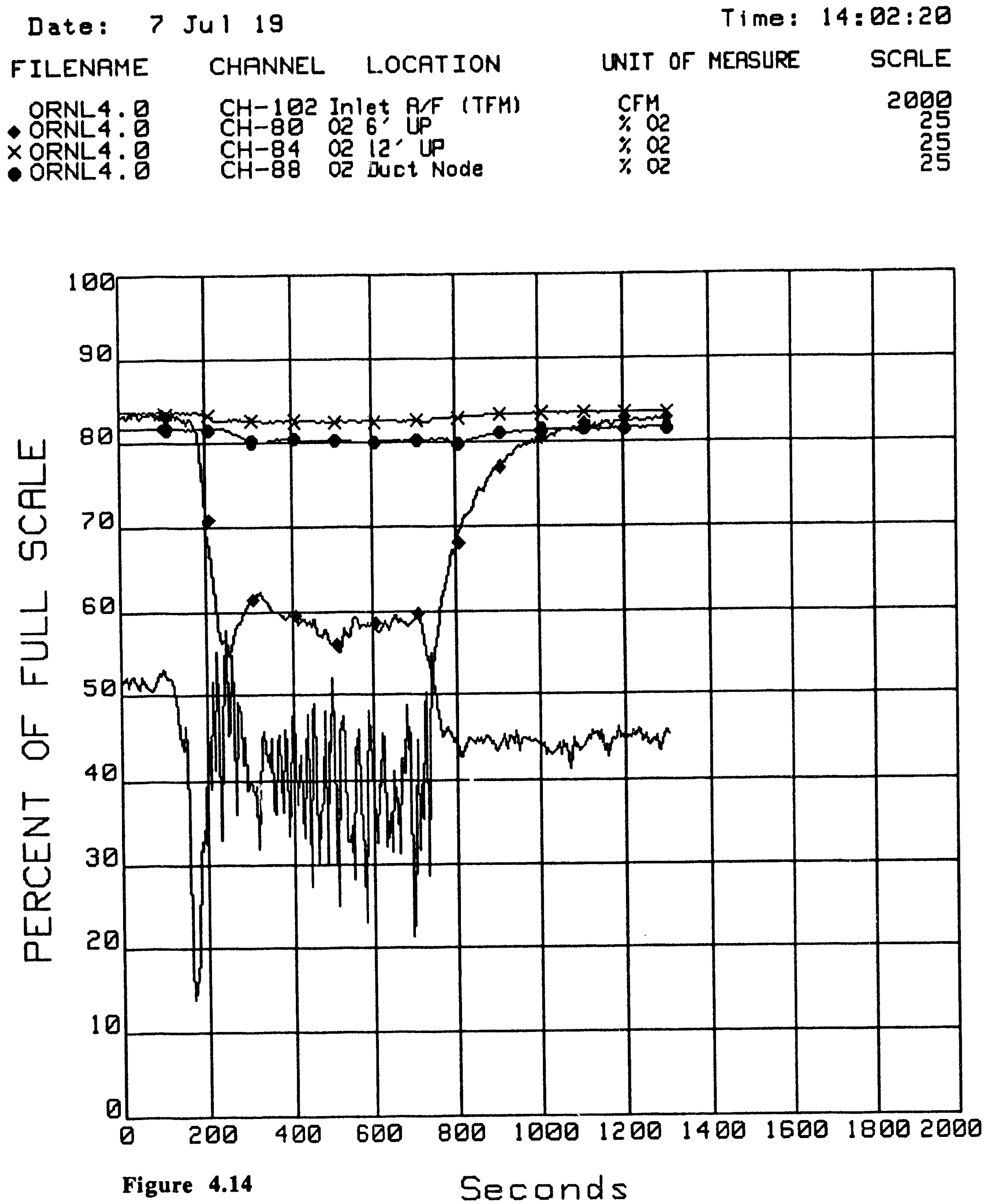

Date: 7 Jul 19
Time: 14:02:20
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL4.0 CH-102 Inlet A/F (TFM) CFM 2000
ORNL4.0 CH-80 O2 6' UP % O2 25
ORNL4.0 CH-84 O2 12' UP % O2 25
ORNL4.0 CH-88 O2 Duct Node % O2 25
PERCENT OF FULL SCALE
Seconds
0 10 20 30 40 50 60 70 80 90 100
0 200 400 600 800 1000 1200 1400 1600 1800 2000

Figure 4.14

Date: 15 Jul 19 Time: 10:52:15

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL5.0	CH-0	NE TC RAKE 6" UP	Degrees Celsius	1200
◆ ORNL5.0	CH-1	NE TC RAKE 2' UP	Degrees Celsius	1200
× ORNL5.0	CH-2	NE TC RAKE 4' UP	Degrees Celsius	1200
● ORNL5.0	CH-3	NE TC RAKE 6' UP	Degrees Celsius	1200
■ ORNL5.0	CH-4	NE TC RAKE 8' UP	Degrees Celsius	1200
◇ ORNL5.0	CH-5	NE TC RAKE 10' UP	Degrees Celsius	1200

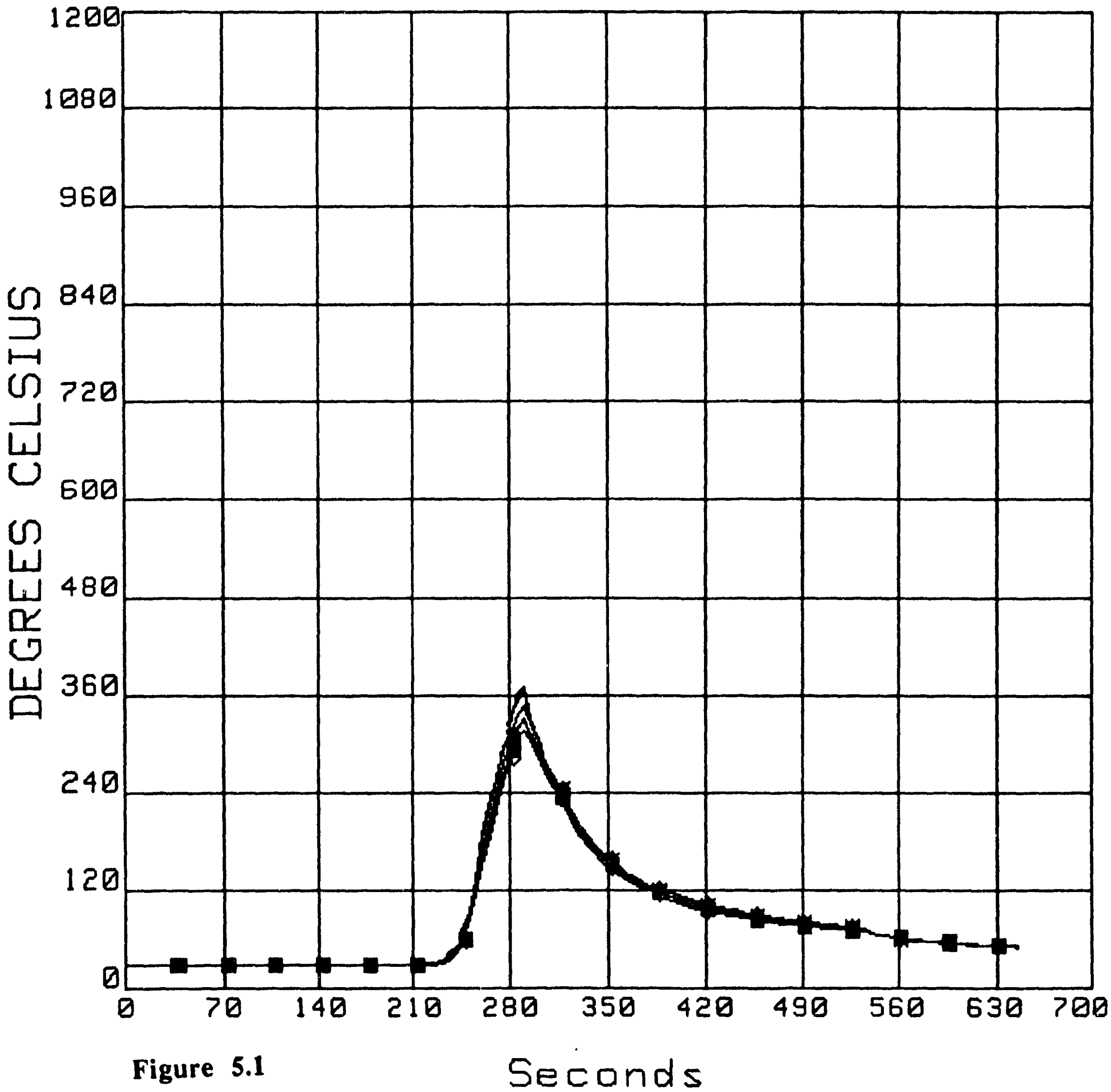


Figure 5.1

Date: 15 Jul 19 Time: 10:52:15

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL5.0	CH-6	NE TC RAKE 12' UP	Degrees Celsius	1200
◆ ORNL5.0	CH-7	NE TC RAKE 14' UP	Degrees Celsius	1200
× ORNL5.0	CH-8	NE TC RAKE 16' UP	Degrees Celsius	1200
● ORNL5.0	CH-9	NE TC RAKE 18' UP	Degrees Celsius	1200
■ ORNL5.0	CH-10	NE TC RAKE 20' UP	Degrees Celsius	1200
◇ ORNL5.0	CH-11	NE TC RAKE 6" DOWN	Degrees Celsius	1200

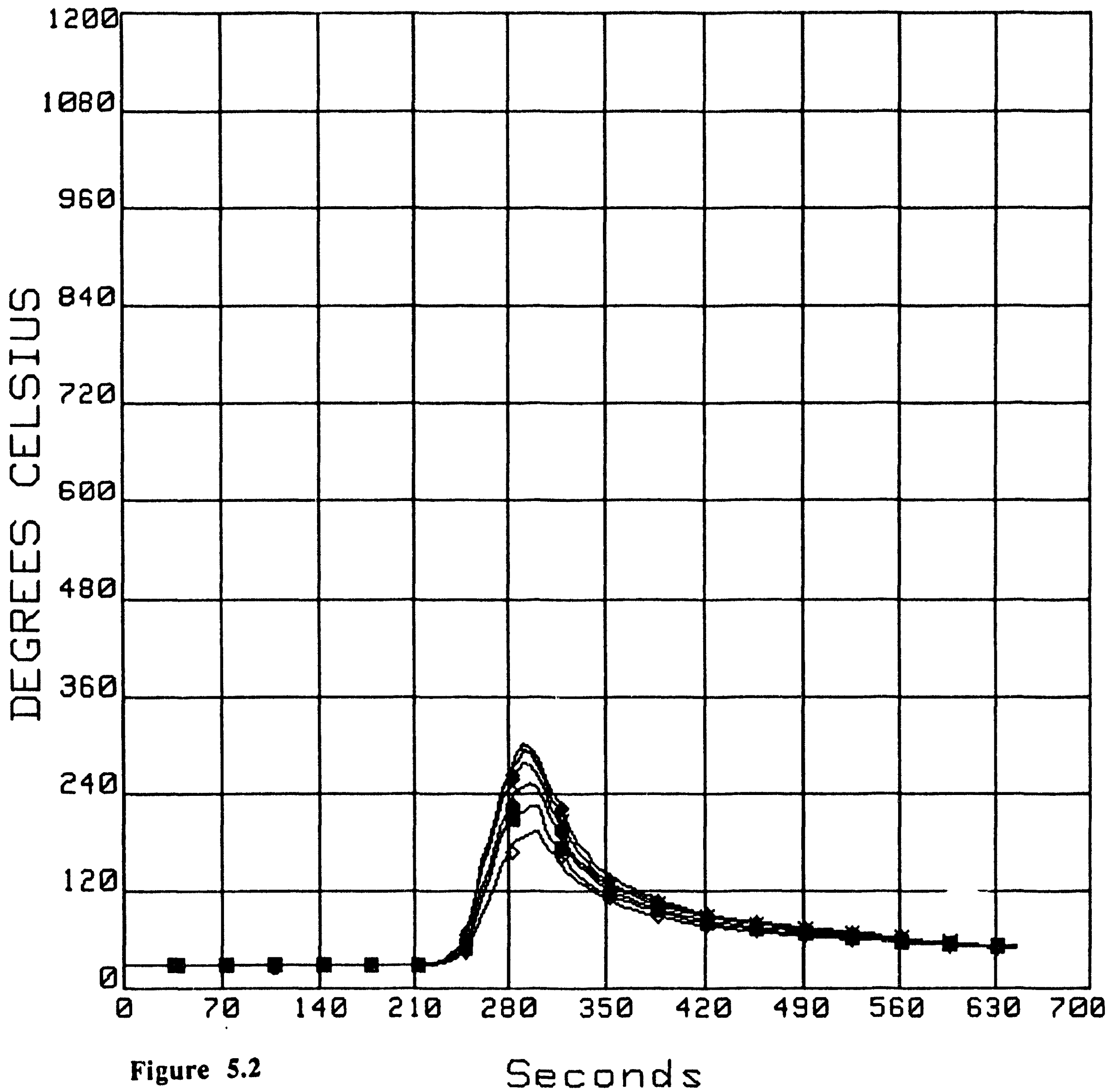


Figure 5.2

Date: 15 Jul 19 Time: 10:52:15

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL5.0	CH-20	So TC RAKE 6" UP	Degrees Celsius	1200
◆ ORNL5.0	CH-21	So TC RAKE 2' UP	Degrees Celsius	1200
× ORNL5.0	CH-22	So TC RAKE 4' UP	Degrees Celsius	1200
● ORNL5.0	CH-23	So TC RAKE 6' UP	Degrees Celsius	1200

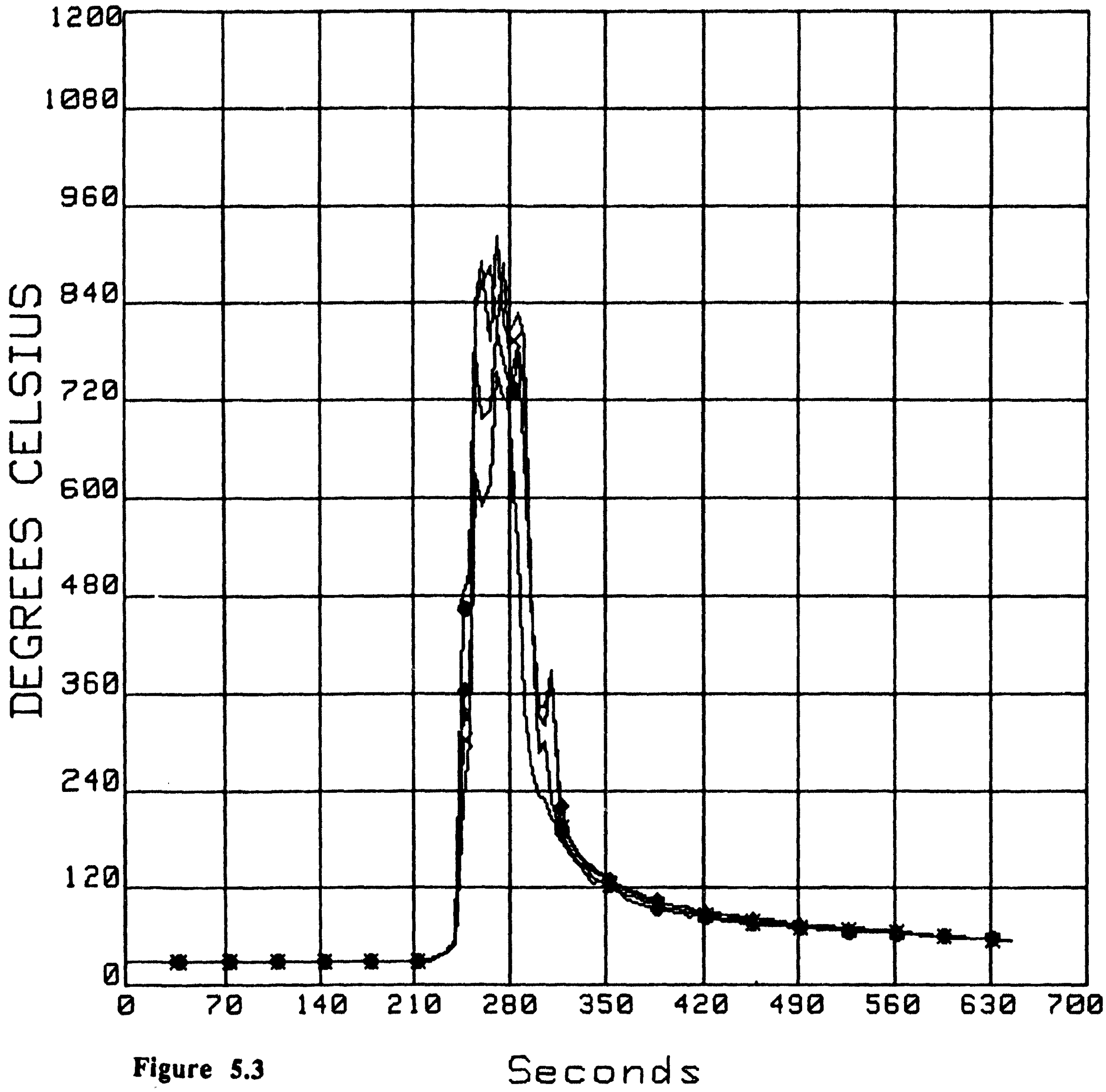


Figure 5.3

Date: 15 Jul 19 Time: 10:52:15

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL5.0	CH-27	TOP So WINDOW TC	Degrees Celsius	1200
◆ ORNL5.0	CH-28	TOP No WINDOW TC	Degrees Celsius	1200
× ORNL5.0	CH-29	BOTTOM So WINDOW TC	Degrees Celsius	1200
● ORNL5.0	CH-30	BOTTOM No WINDOW TC	Degrees Celsius	1200

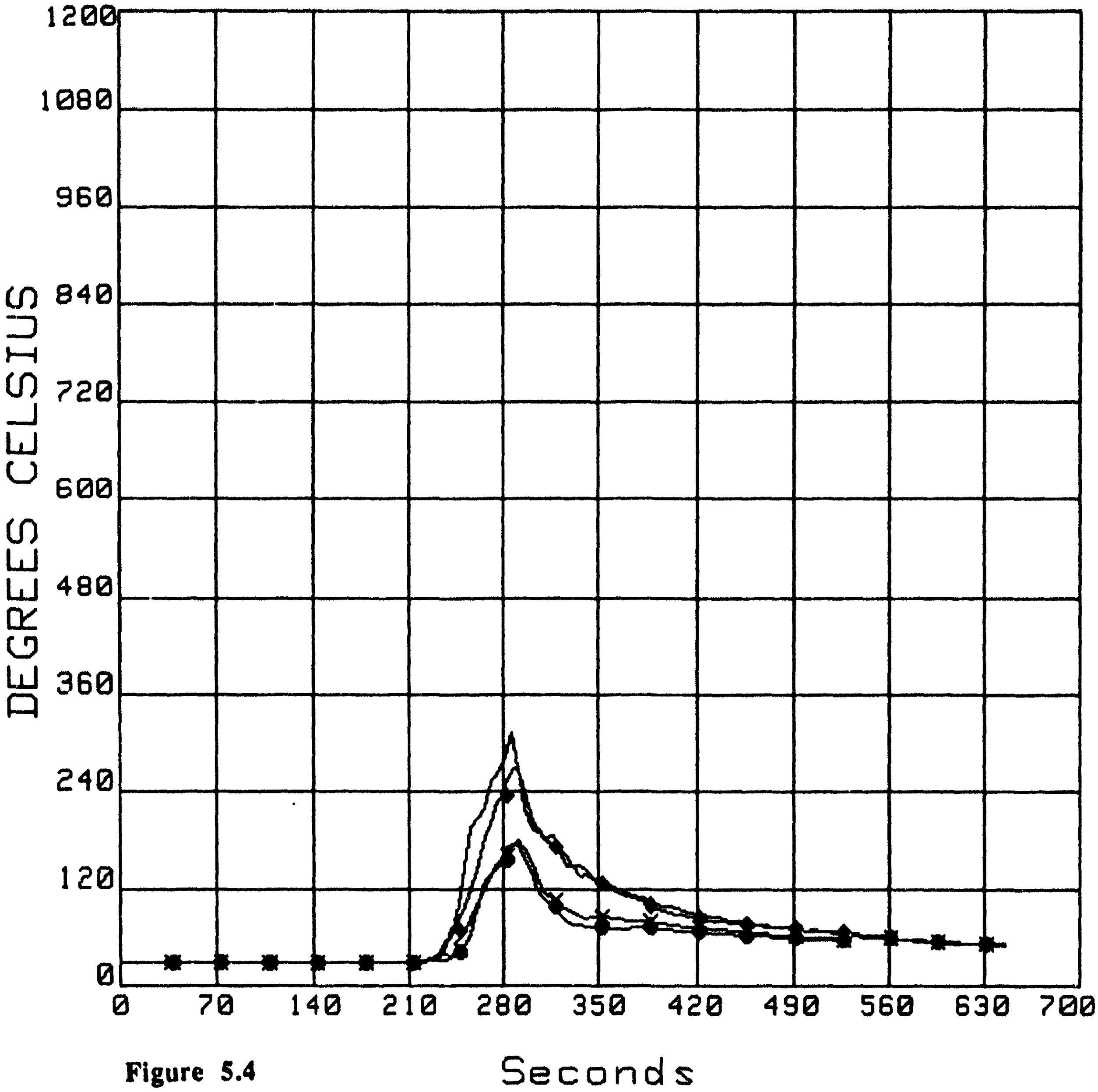


Figure 5.4

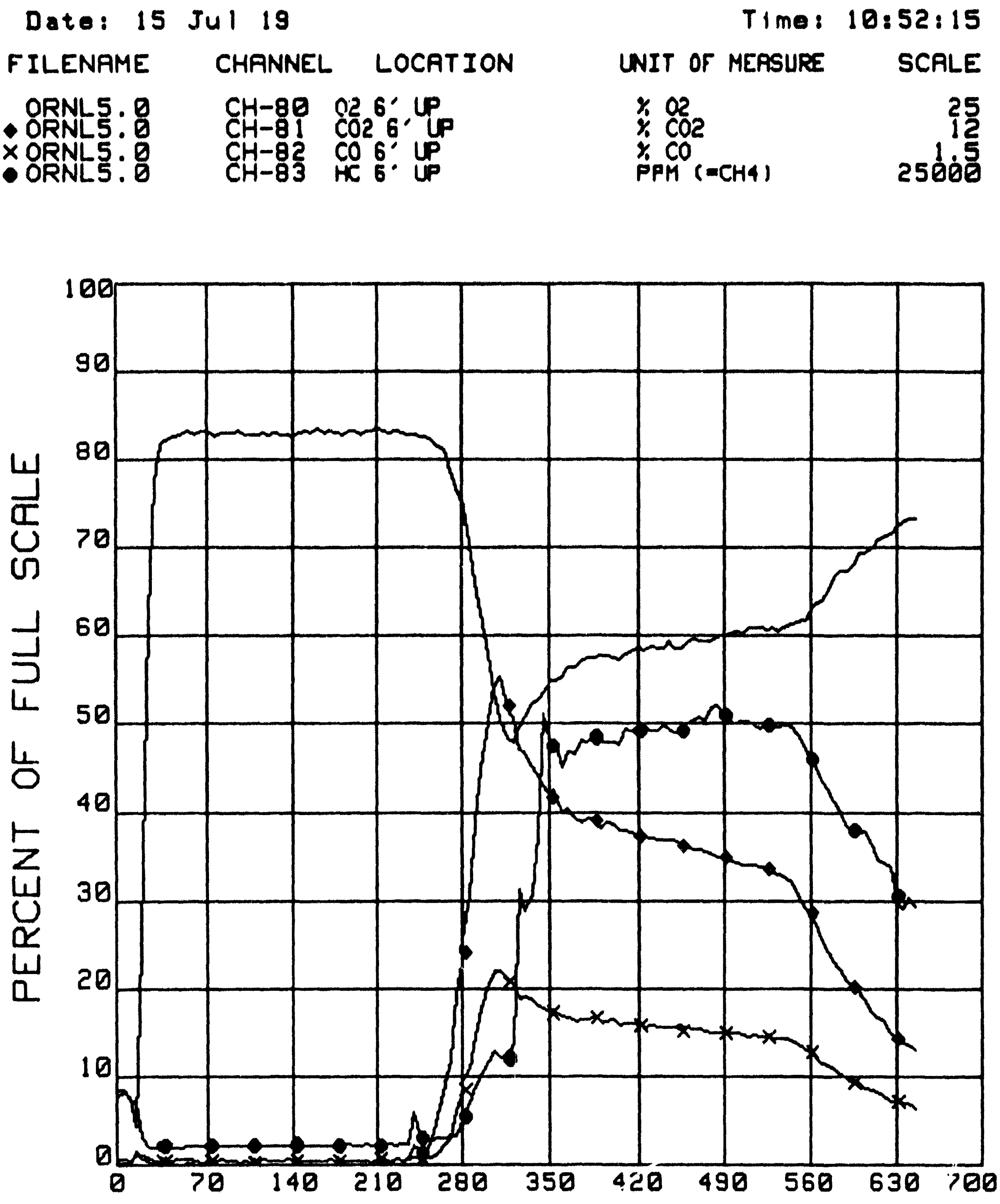

Date: 15 Jul 19
Time: 10:52:15
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL5.0 CH-80 O2 6' UP % O2 25
ORNL5.0 CH-81 CO2 6' UP % CO2 12
ORNL5.0 CH-82 CO 6' UP % CO 1.5
ORNL5.0 CH-83 HC 6' UP PPM (=CH4) 25000
PERCENT OF FULL SCALE
0 10 20 30 40 50 60 70 80 90 100
0 70 140 210 280 350 420 490 560 630 700
Seconds

Figure 5.5

Date: 15 Jul 19 Time: 10:52:15

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL5.0	CH-95	Near Cell	% Transmittance	100
◆ ORNL5.0	CH-96	Before Filters	% Transmittance	100

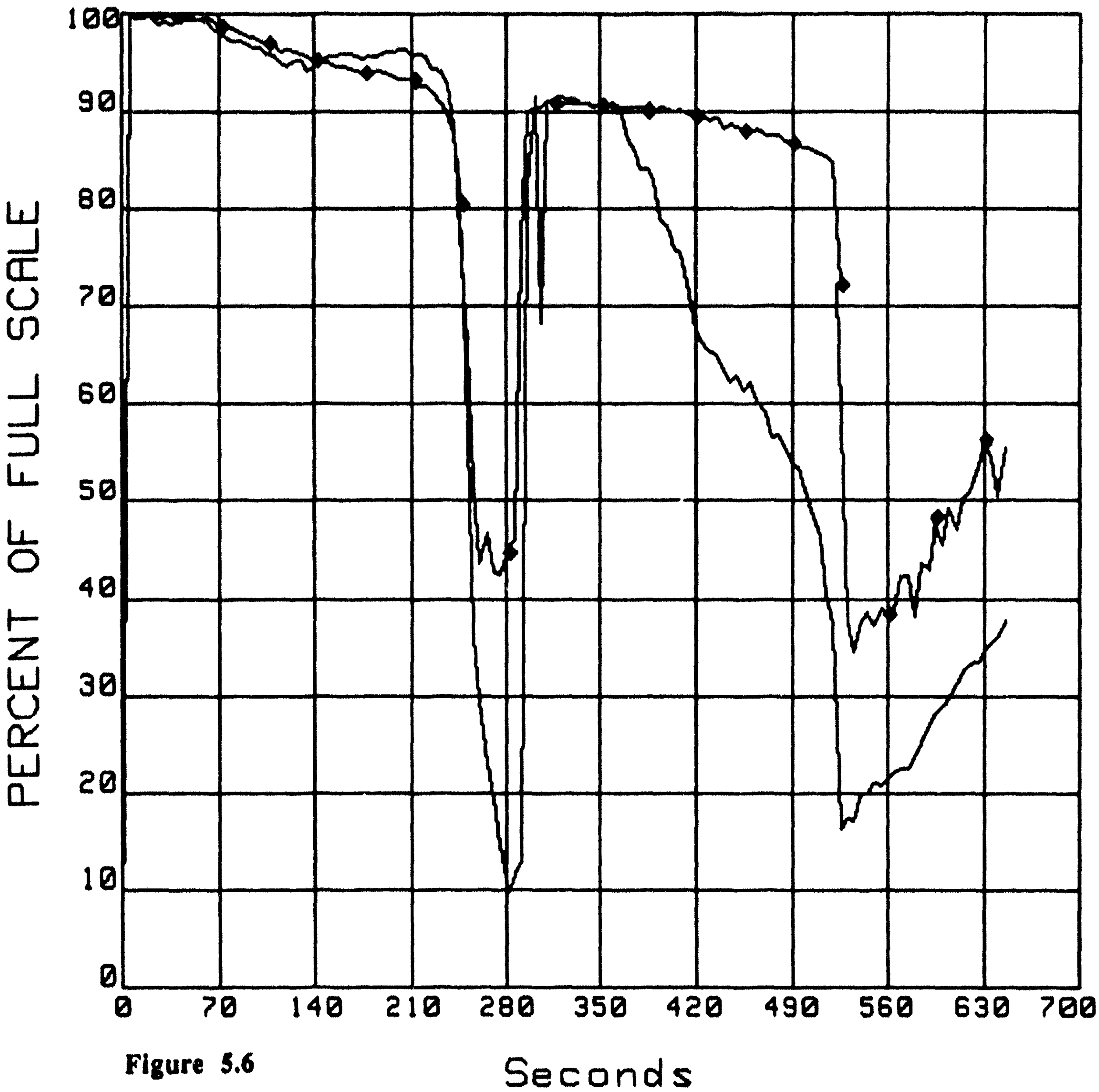


Figure 5.6

Date: 15 Jul 19 Time: 10:52:15

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL5.0	CH-102	Inlet A/F (TFM)	CFM	5000
◆ ORNL5.0	CH-104	Exit A/F (Pitot)	CFM	5000
× ORNL5.0	CH-105	Exit A/F (TFM)	CFM	5000

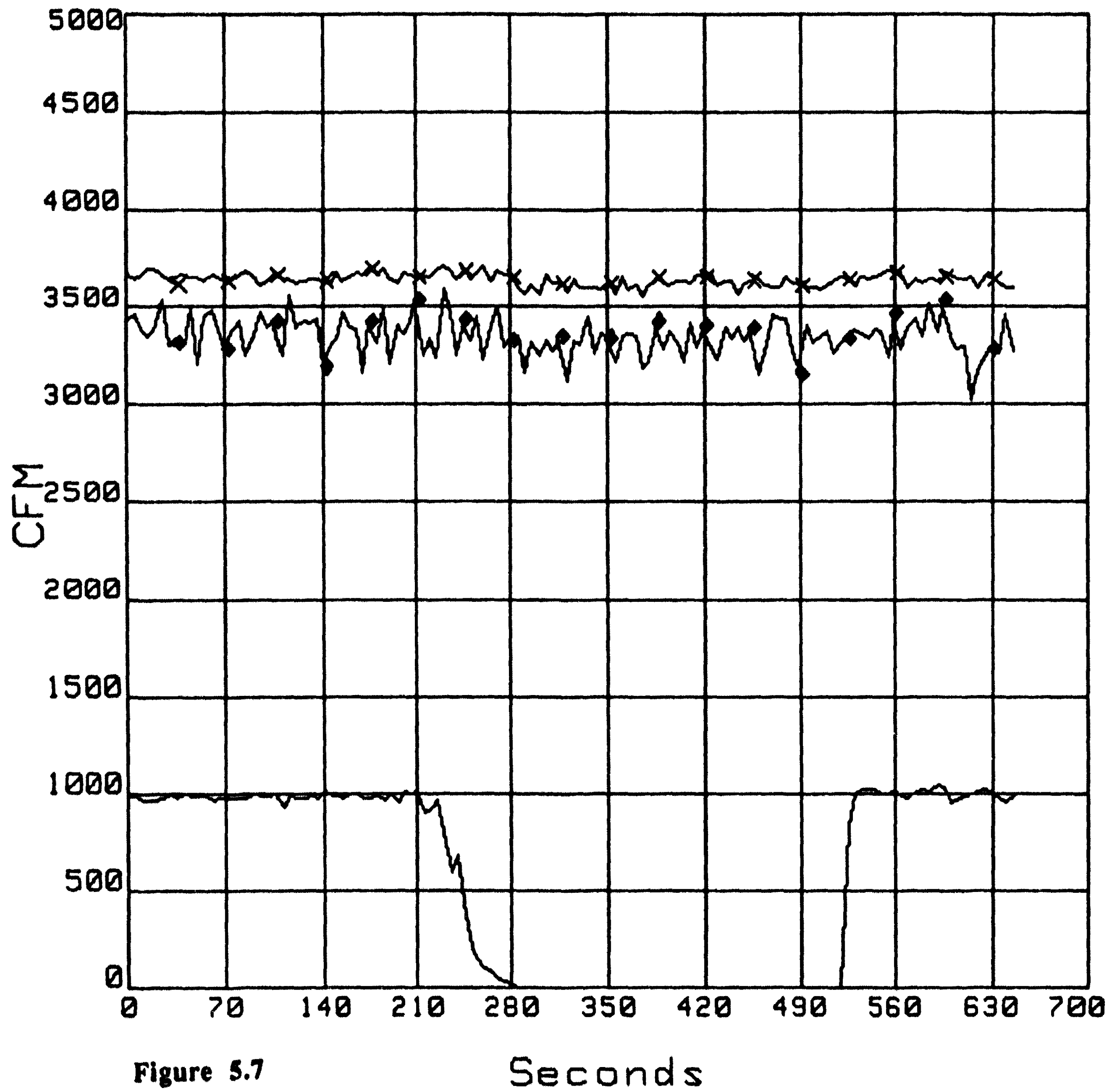


Figure 5.7

Date: 15 Jul 19 Time: 10:52:15

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL5.0	CH-109	Delta P HEPA	INCHES H20	5
◆ ORNL5.0	CH-110	Delta P PreFilter	INCHES H20	5

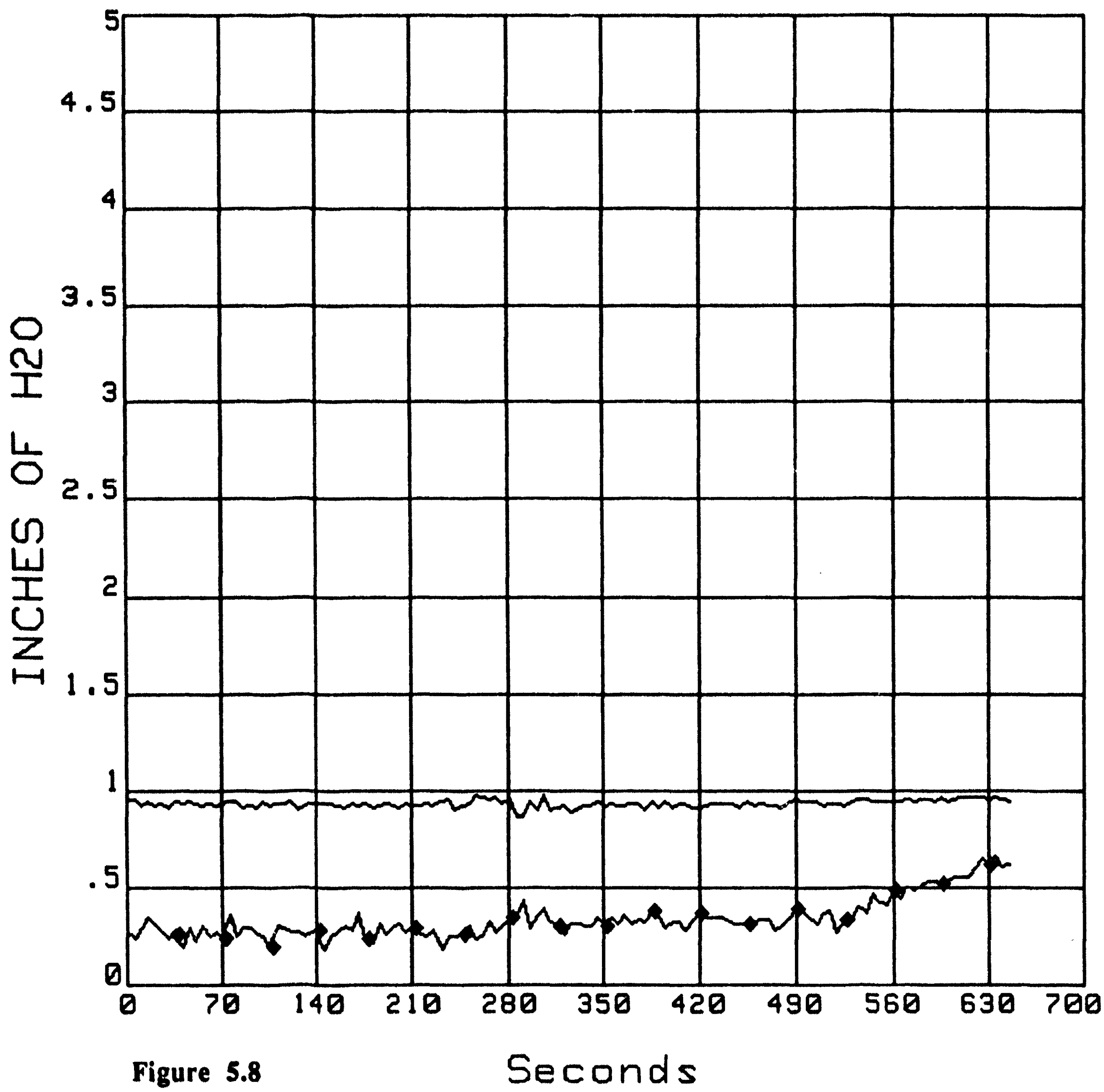
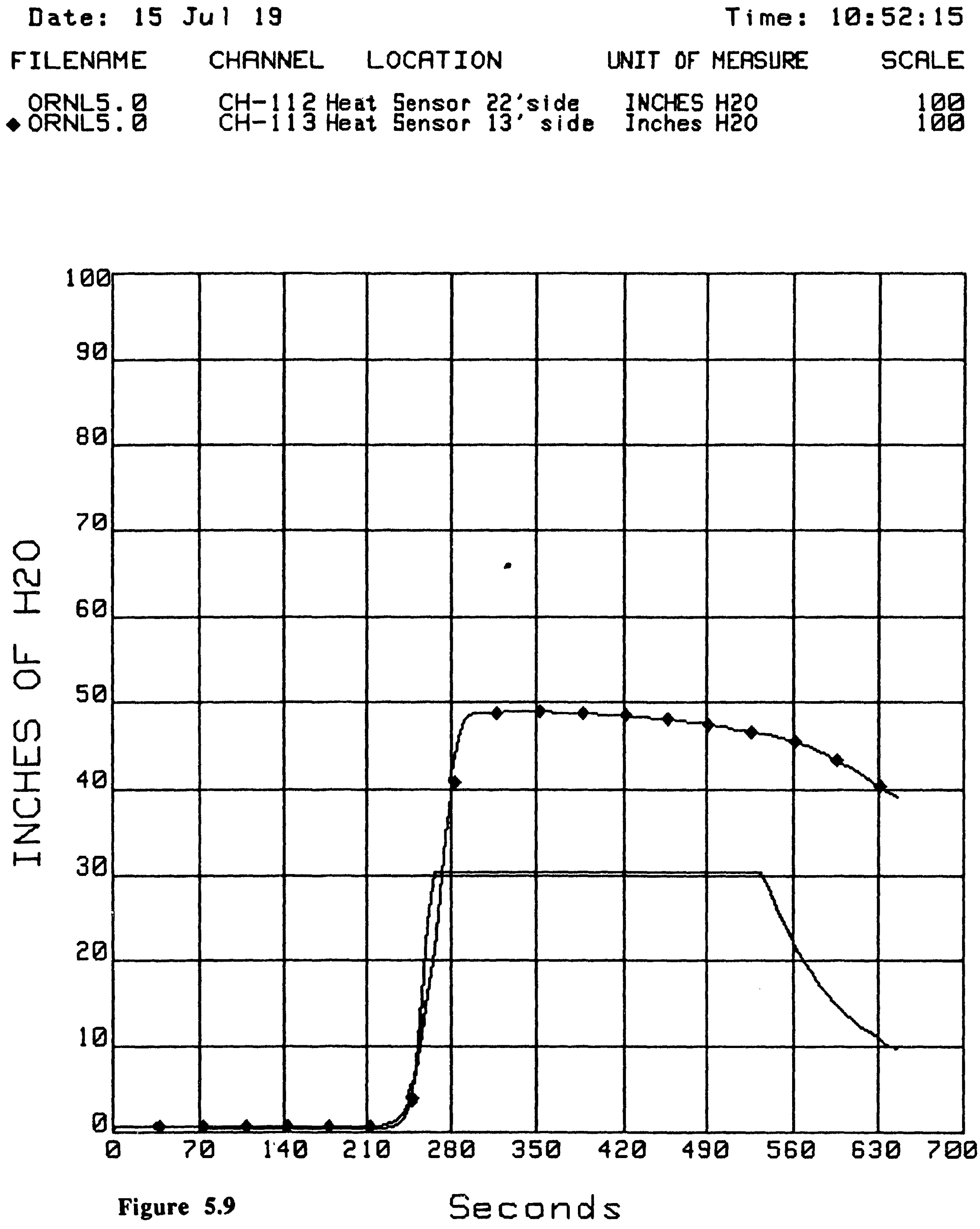


Figure 5.8



Date: 15 Jul 19
Time: 10:52:15
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL5.0 CH-112 Heat Sensor 22'side INCHES H20 100
◆ORNL5.0 CH-113 Heat Sensor 13' side Inches H20 100
INCHES OF H20
0 10 20 30 40 50 60 70 80 90 100
0 70 140 210 280 350 420 490 560 630 700
Seconds

Figure 5.9

Date: 15 Jul 19 Time: 10:52:15

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL5.0	CH-32	CELL MANIFOLD TC	Degrees Celsius	300
◆ ORNL5.0	CH-34	CEL EXH DUCT TC	Degrees Celsius	300
× ORNL5.0	CH-35	EXH/MAKEUP NODE TC	Degrees Celsius	300
● ORNL5.0	CH-36	TC BEFORE PREFILTER	Degrees Celsius	300
■ ORNL5.0	CH-37	TC BEFORE HEPA	Degrees Celsius	300

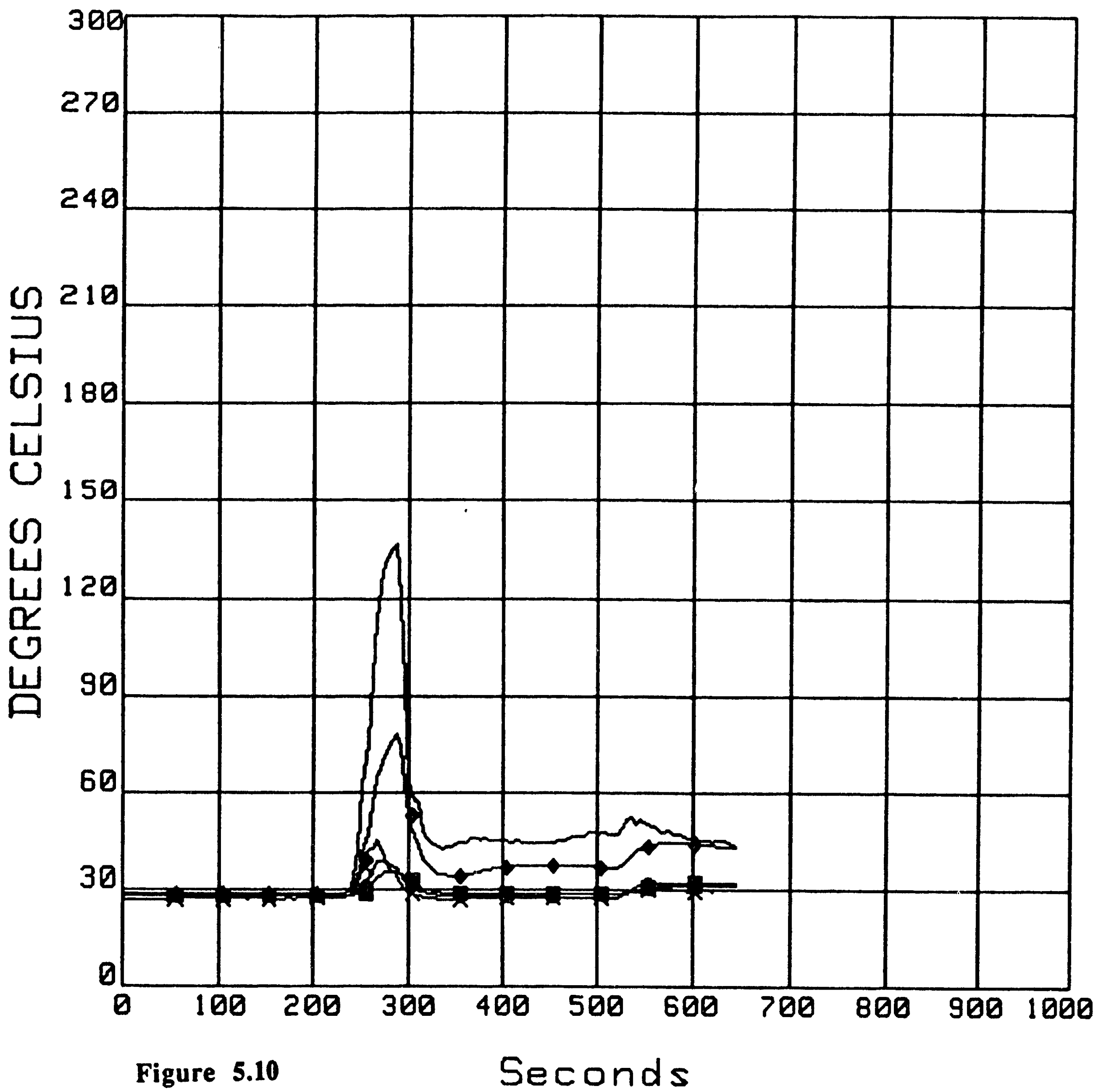


Figure 5.10

Date: 15 Jul 19 Time: 10:52:15

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL5.0	CH-84	O2 12' UP	% O2	25
◆ ORNL5.0	CH-85	CO2 12' UP	% CO2	12
× ORNL5.0	CH-86	CO 12' UP	% CO	1.5
● ORNL5.0	CH-87	HC 12'UP	PPM (=CH4)	25000

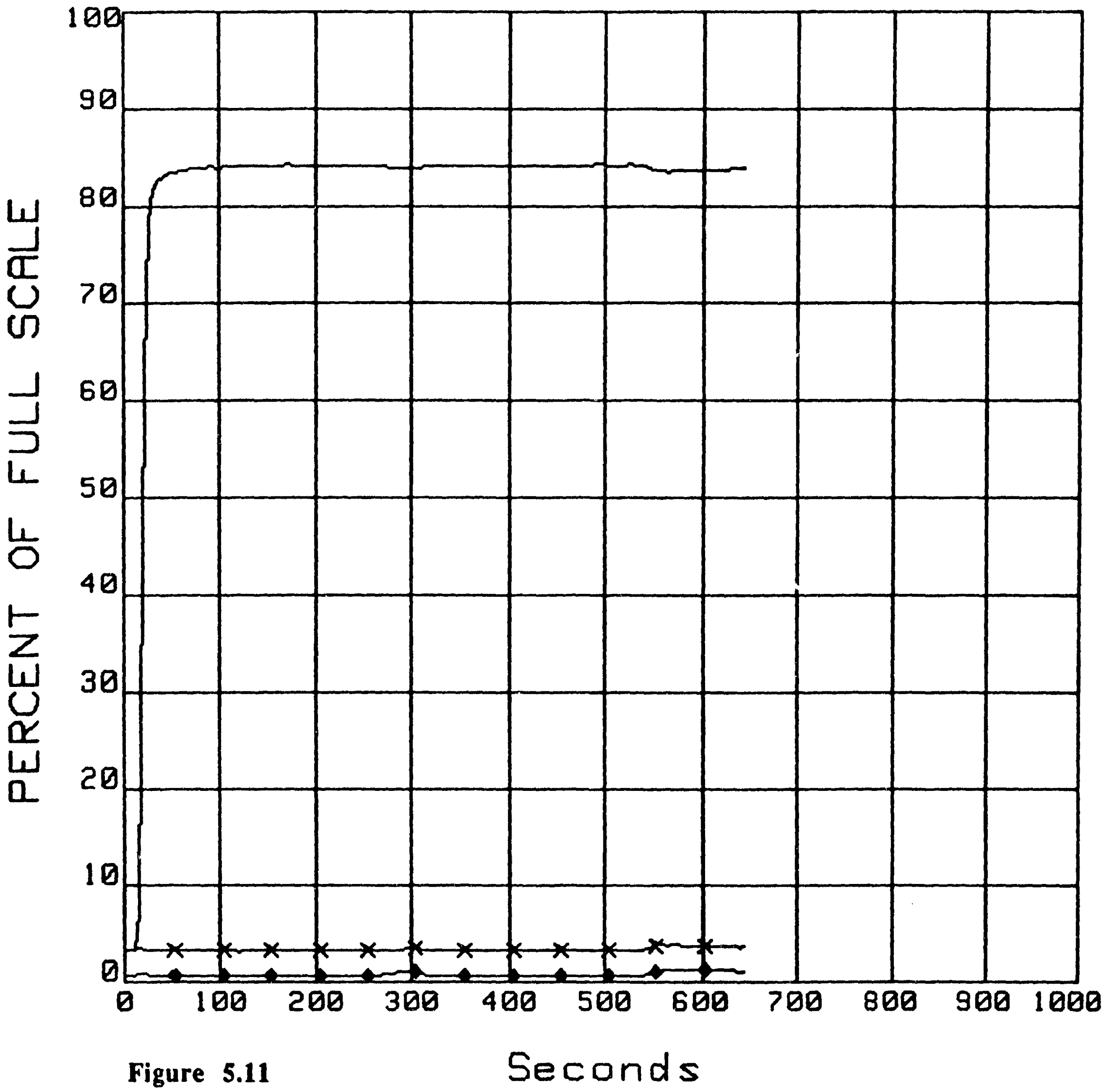


Figure 5.11

Date: 15 Jul 19 Time: 10:52:15

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL5.0	CH-88	O2 Duct Node	% O2	25
◆ ORNL5.0	CH-89	CO2 Duct Node	% CO2	12
× ORNL5.0	CH-90	CO Duct Node	% CO	1.5
● ORNL5.0	CH-91	HC Duct Node	PPM (=CH4)	25000

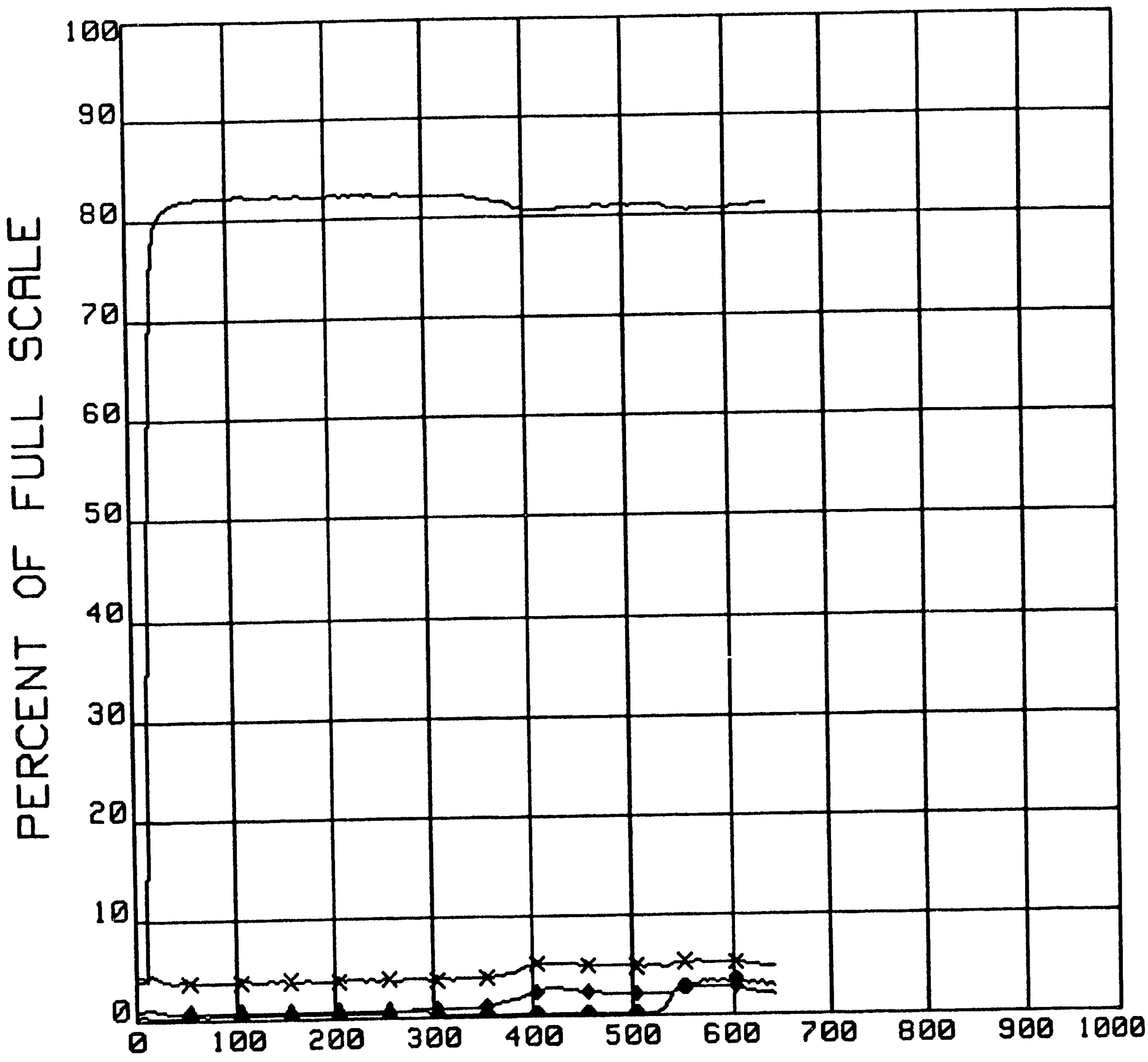


Figure 5.12

Date: 15 Jul 19 Time: 10:52:15

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL5.0	CH-102	Inlet A/F (TFM)	CFM	2000
◆ ORNL5.0	CH-80	O2 6' UP	% O2	25
× ORNL5.0	CH-84	O2 12' UP	% O2	25
● ORNL5.0	CH-88	O2 Duct Node	% O2	25

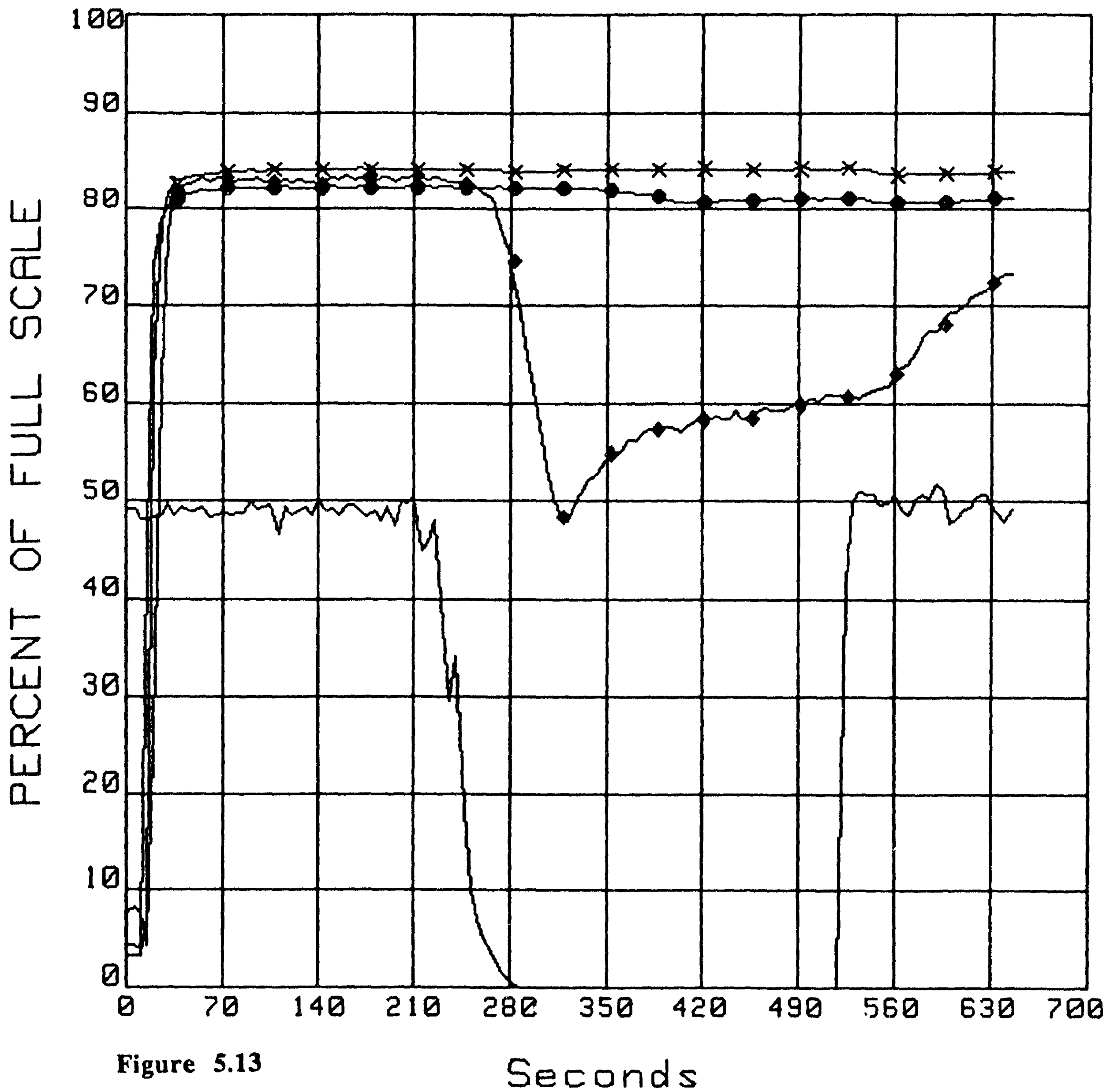


Figure 5.13

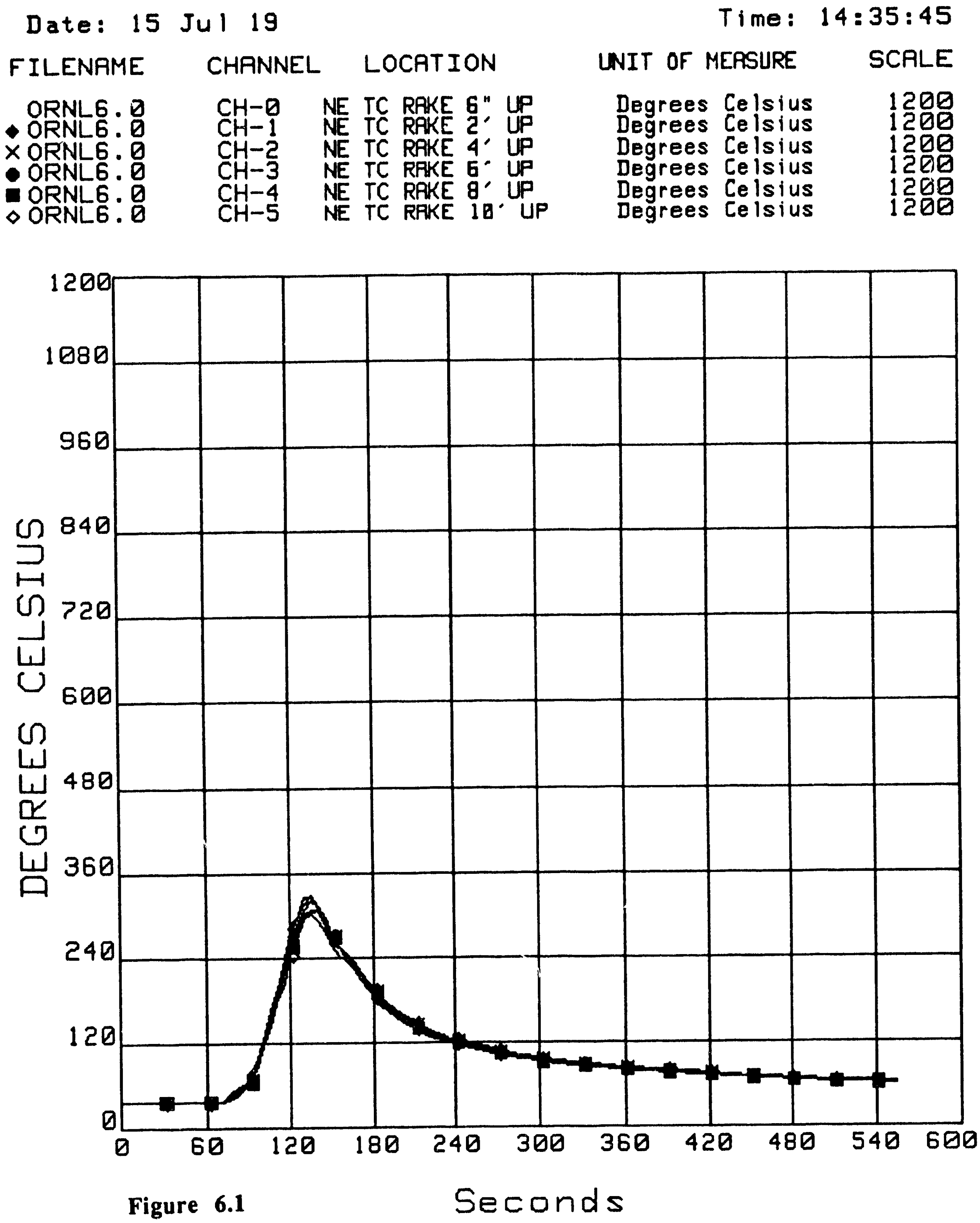

Date: 15 Jul 19
Time: 14:35:45
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL6.0 CH-0 NE TC RAKE 6" UP Degrees Celsius 1200
ORNL6.0 CH-1 NE TC RAKE 2′ UP Degrees Celsius 1200
ORNL6.0 CH-2 NE TC RAKE 4′ UP Degrees Celsius 1200
ORNL6.0 CH-3 NE TC RAKE 6′ UP Degrees Celsius 1200
ORNL6.0 CH-4 NE TC RAKE 8′ UP Degrees Celsius 1200
ORNL6.0 CH-5 NE TC RAKE 10′ UP Degrees Celsius 1200
DEGREES CELSIUS
1200
1080
960
840
720
600
480
360
240
120
0
0
60
120
180
240
300
360
420
480
540
600
Seconds

Figure 6.1

Date: 15 Jul 19 Time: 14:35:45

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL6.0	CH-6	NE TC RAKE 12' UP	Degrees Celsius	1200
◆ ORNL6.0	CH-7	NE TC RAKE 14' UP	Degrees Celsius	1200
× ORNL6.0	CH-8	NE TC RAKE 16' UP	Degrees Celsius	1200
● ORNL6.0	CH-9	NE TC RAKE 18' UP	Degrees Celsius	1200
■ ORNL6.0	CH-10	NE TC RAKE 20' UP	Degrees Celsius	1200
◇ ORNL6.0	CH-11	NE TC RAKE 6" DOWN	Degrees Celsius	1200

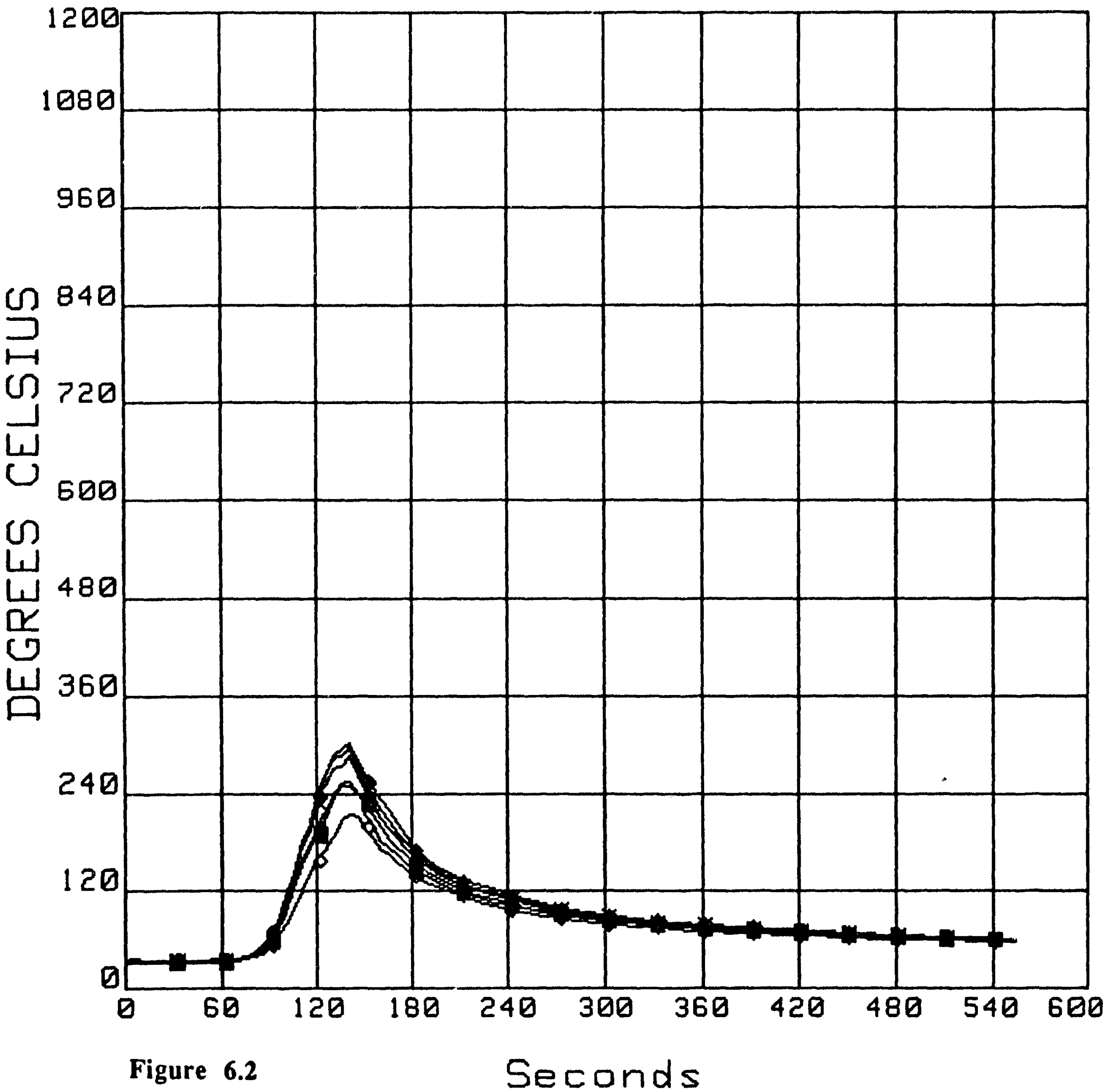


Figure 6.2

Date: 15 Jul 19 Time: 14:35:45

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL6.0	CH-20	So TC RAKE 6" UP	Degrees Celsius	1200
◆ ORNL6.0	CH-21	So TC RAKE 2' UP	Degrees Celsius	1200
× ORNL6.0	CH-22	So TC RAKE 4' UP	Degrees Celsius	1200
● ORNL6.0	CH-23	So TC RAKE 6' UP	Degrees Celsius	1200

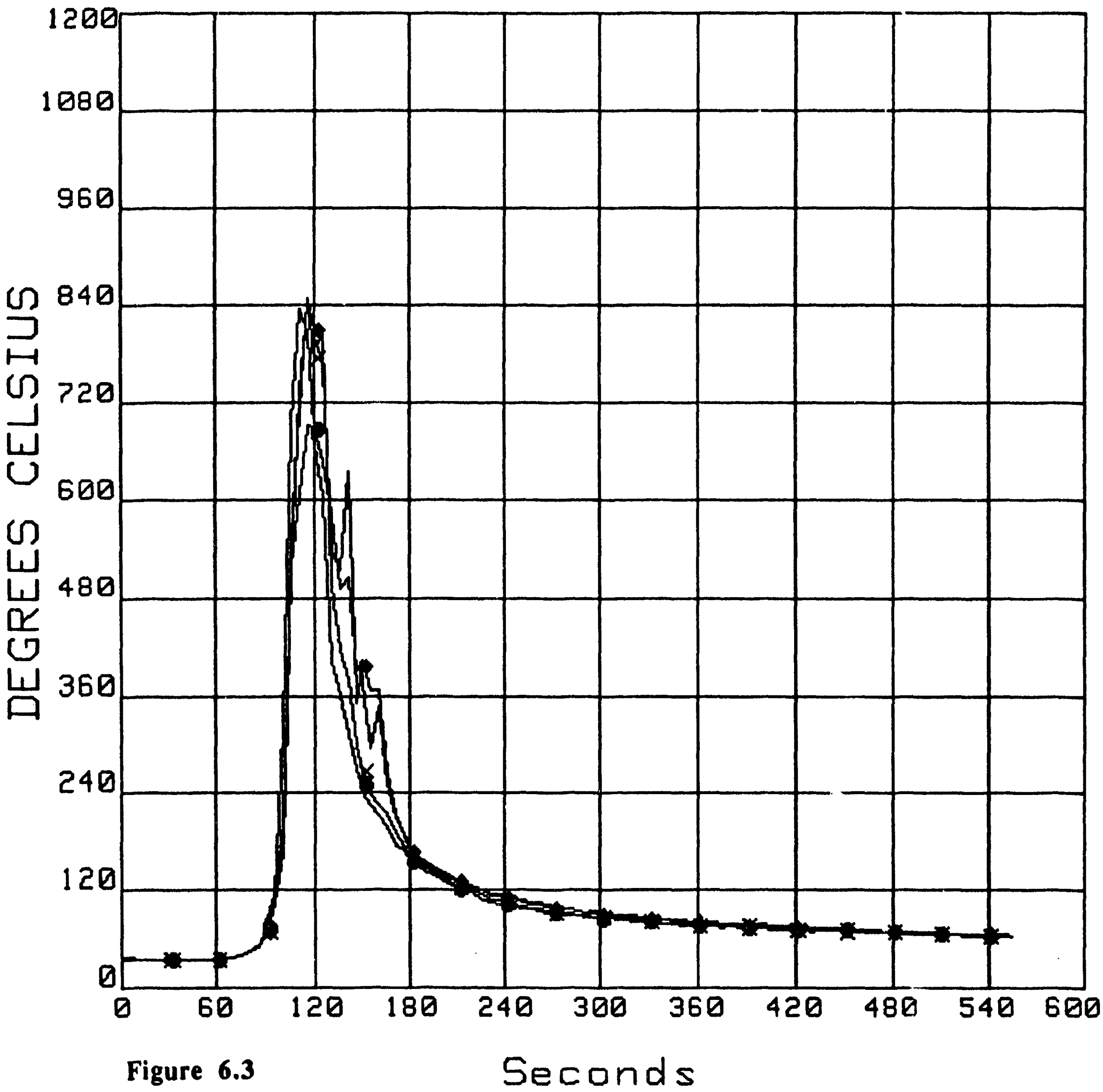


Figure 6.3

Date: 15 Jul 19 Time: 14:35:45

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL6.0	CH-27	TOP So WINDOW TC	Degrees Celsius	1200
◆ ORNL6.0	CH-28	TOP No WINDOW TC	Degrees Celsius	1200
× ORNL6.0	CH-29	BOTTOM So WINDOW TC	Degrees Celsius	1200
● ORNL6.0	CH-30	BOTTOM No WINDOW TC	Degrees Celsius	1200

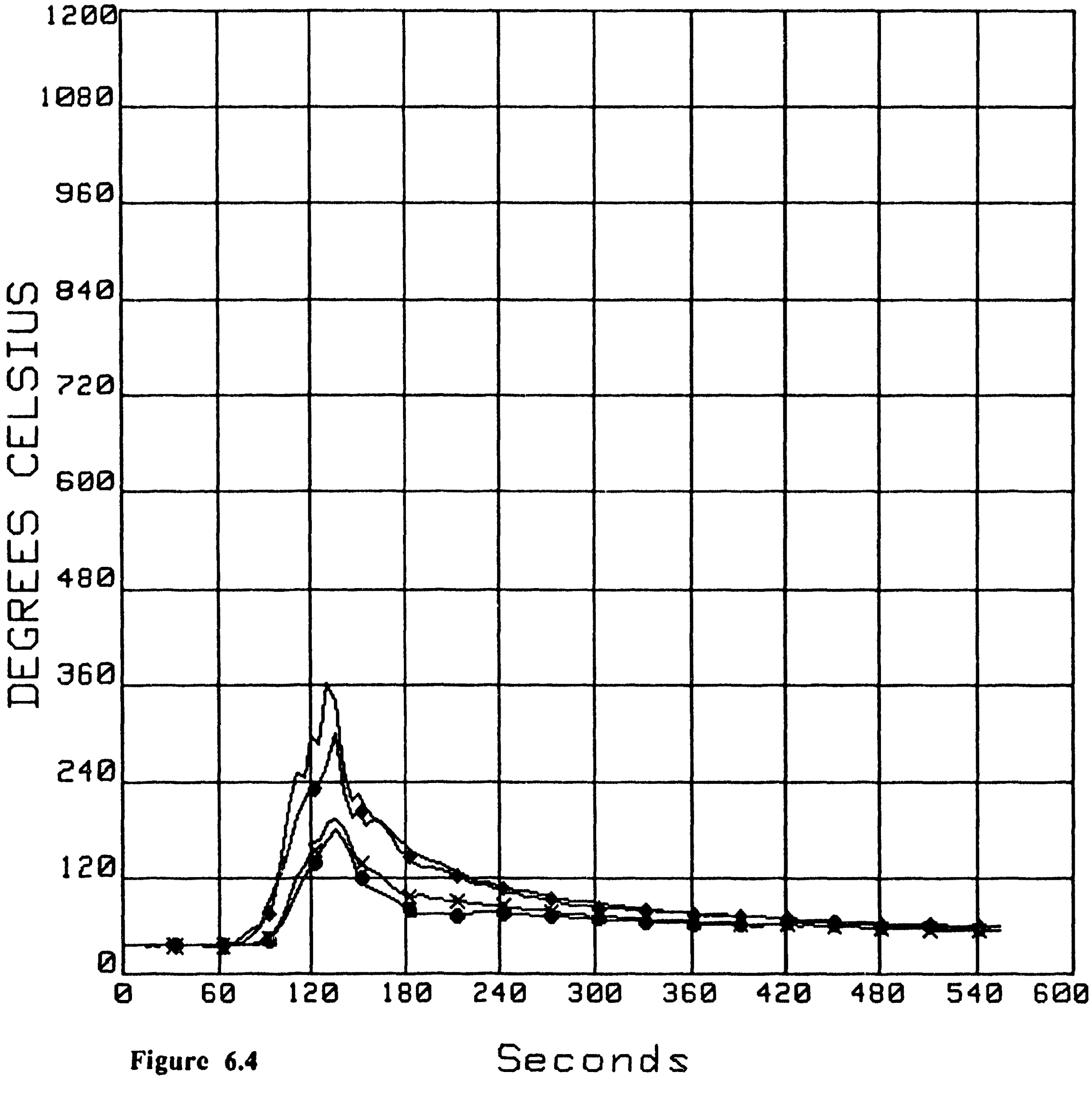


Figure 6.4

Date: 15 Jul 19 Time: 14:35:45

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL6.0	CH-80	O2 6' UP	% O2	25
◆ ORNL6.0	CH-81	CO2 6' UP	% CO2	12
× ORNL6.0	CH-82	CO 6' UP	% CO	1.5
● ORNL6.0	CH-83	HC 6' UP	PPM (=CH4)	25000

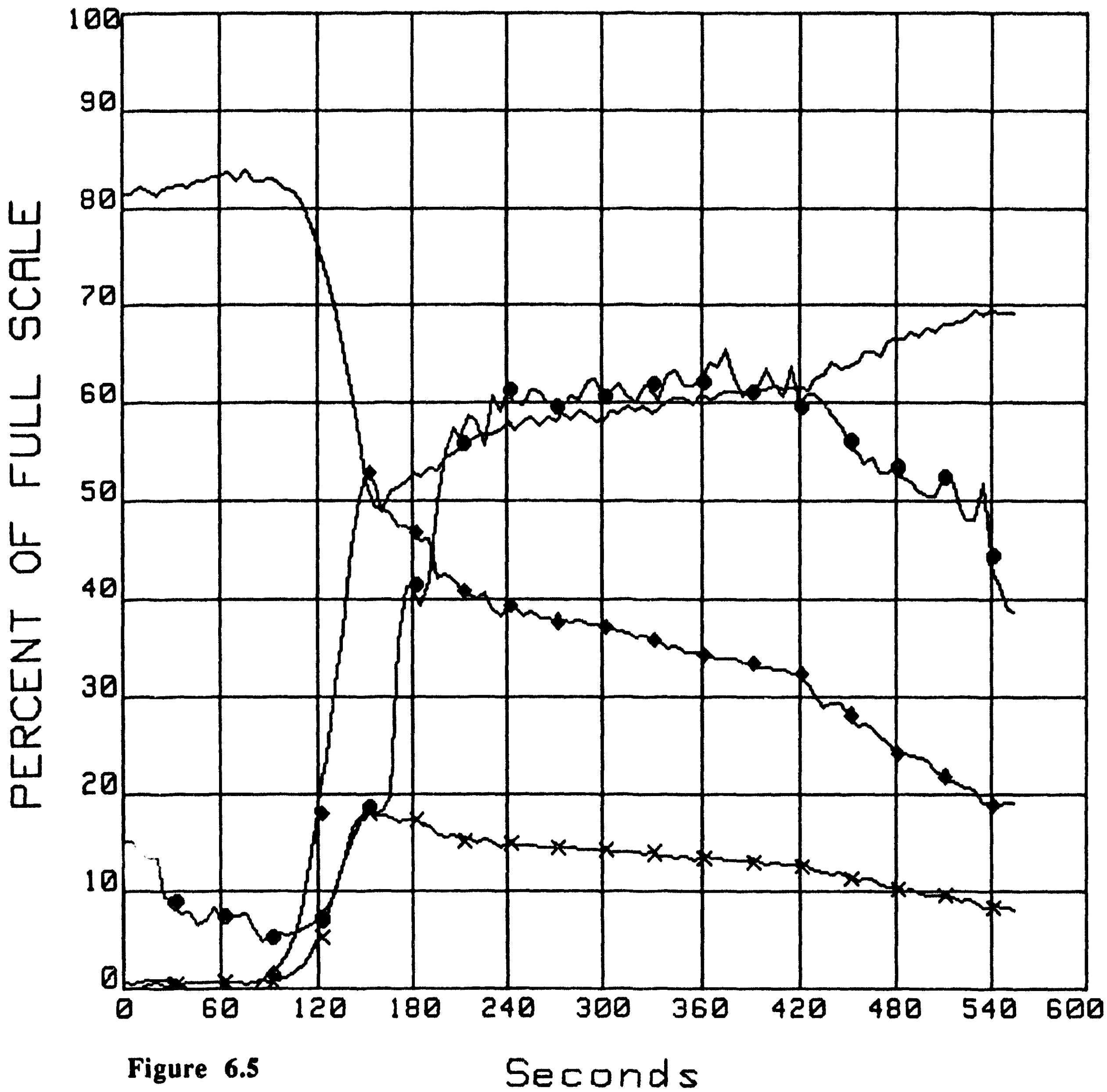


Figure 6.5

Date: 15 Jul 19 Time: 14:35:45

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL6.0	CH-95	Near Cell	% Transmittance	100
◆ ORNL6.0	CH-96	Before Filters	% Transmittance	100

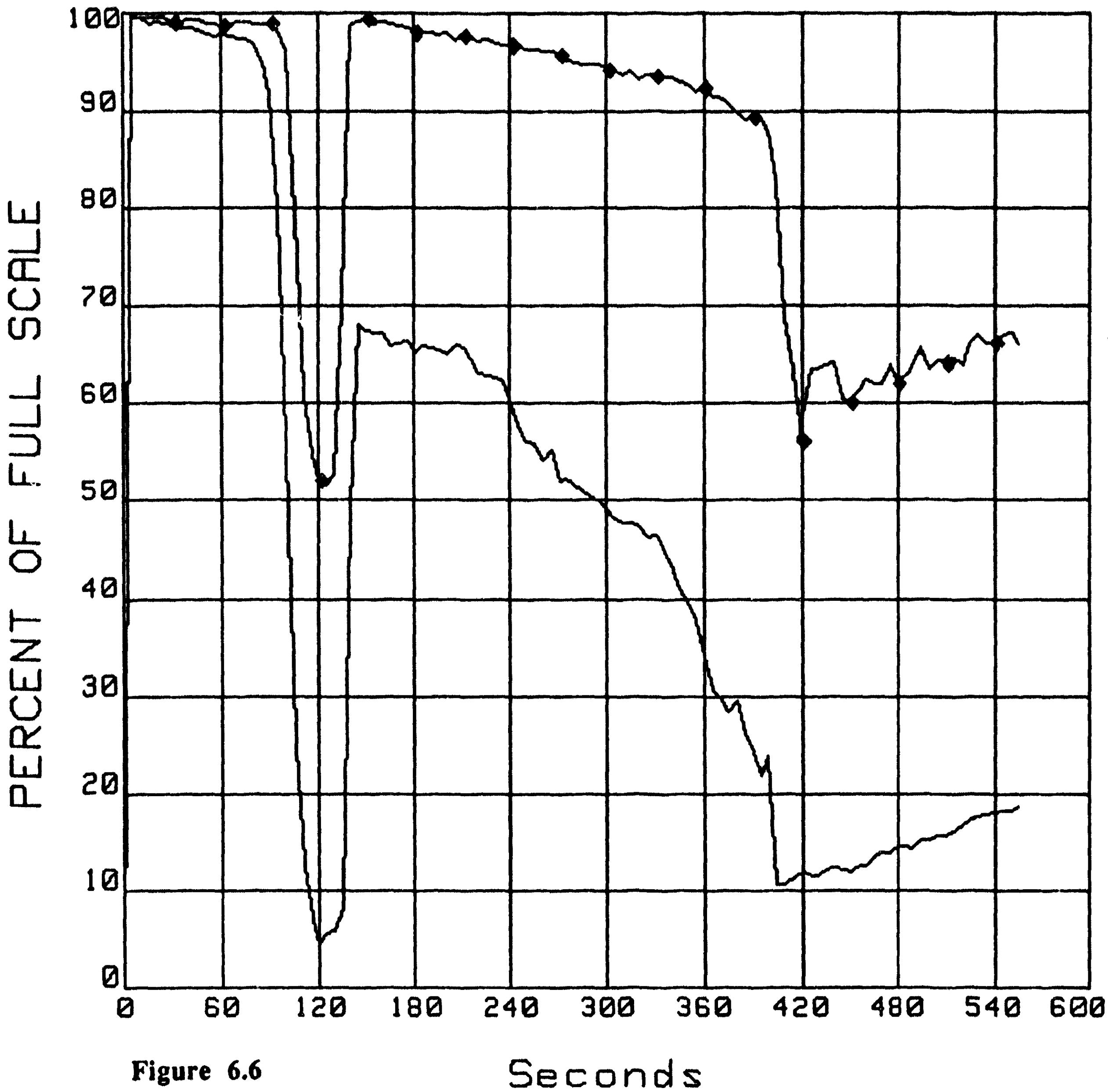


Figure 6.6

Date: 15 Jul 19 Time: 14:35:45

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL6.0	CH-102	Inlet A/F (TFM)	CFM	5000
◆ ORNL6.0	CH-104	Exit A/F (Pitot)	CFM	5000
× ORNL6.0	CH-105	Exit A/F (TFM)	CFM	5000

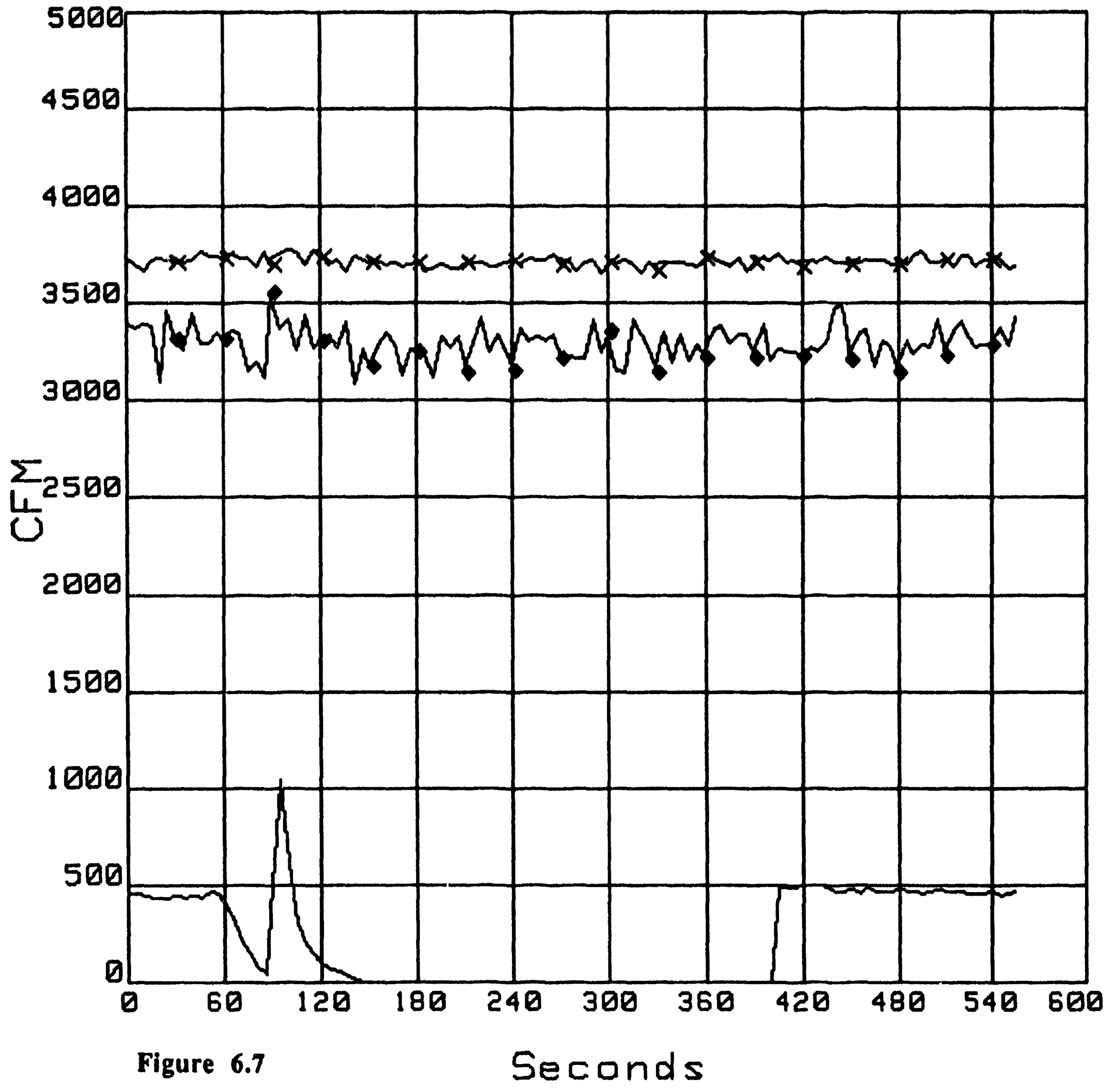
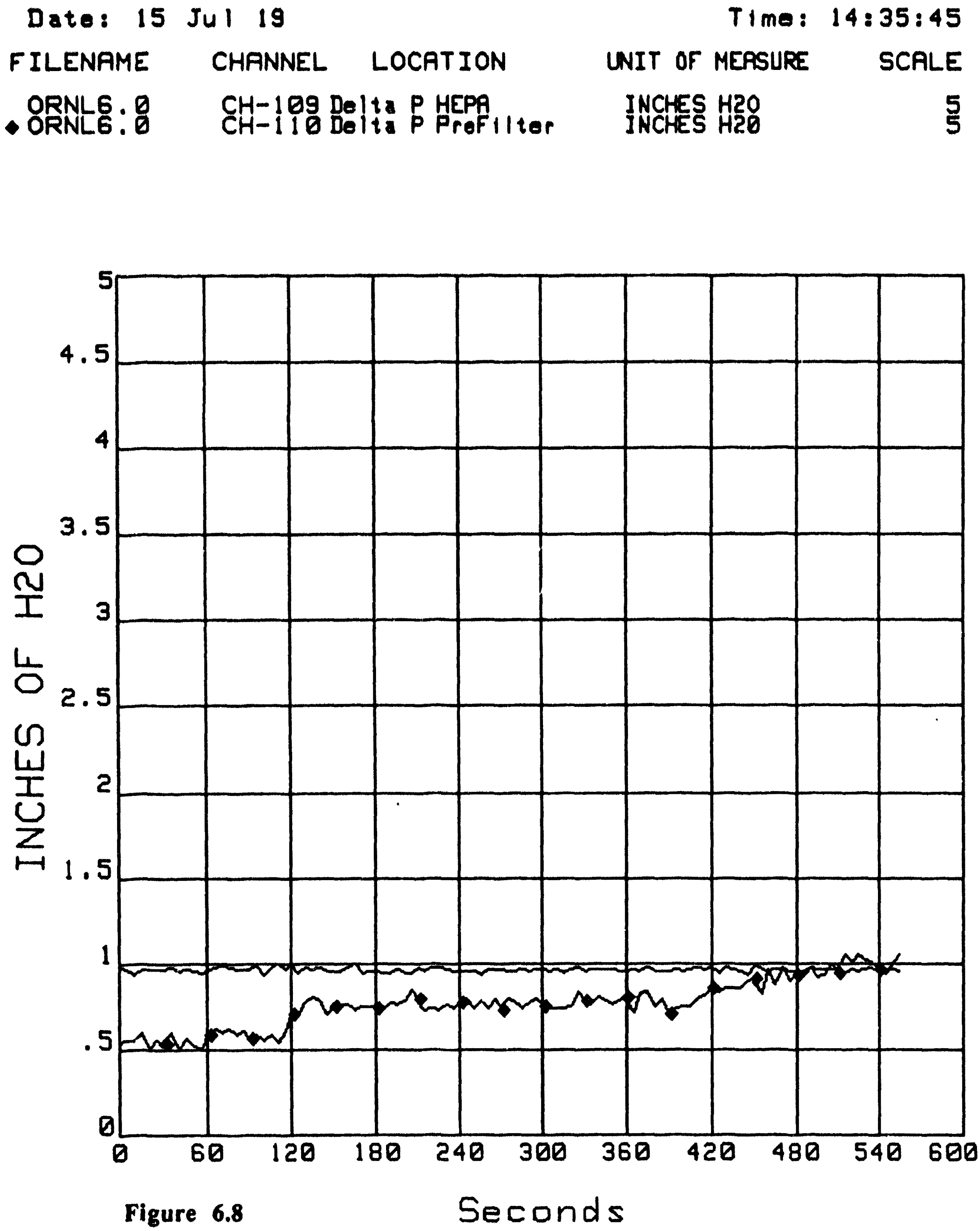


Figure 6.7



Date: 15 Jul 19
Time: 14:35:45
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL6.0 CH-109 Delta P HEPA INCHES H20 5
◆ ORNL6.0 CH-110 Delta P PreFilter INCHES H20 5
INCHES OF H20
5
4.5
4
3.5
3
2.5
2
1.5
1
.5
0
0 60 120 180 240 300 360 420 480 540 600
Seconds

Figure 6.8

Date: 15 Jul 19 Time: 14:35:45

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL6.0	CH-112	Heat Sensor 22'side	INCHES H20	100
◆ ORNL6.0	CH-113	Heat Sensor 13' side	Inches H20	100

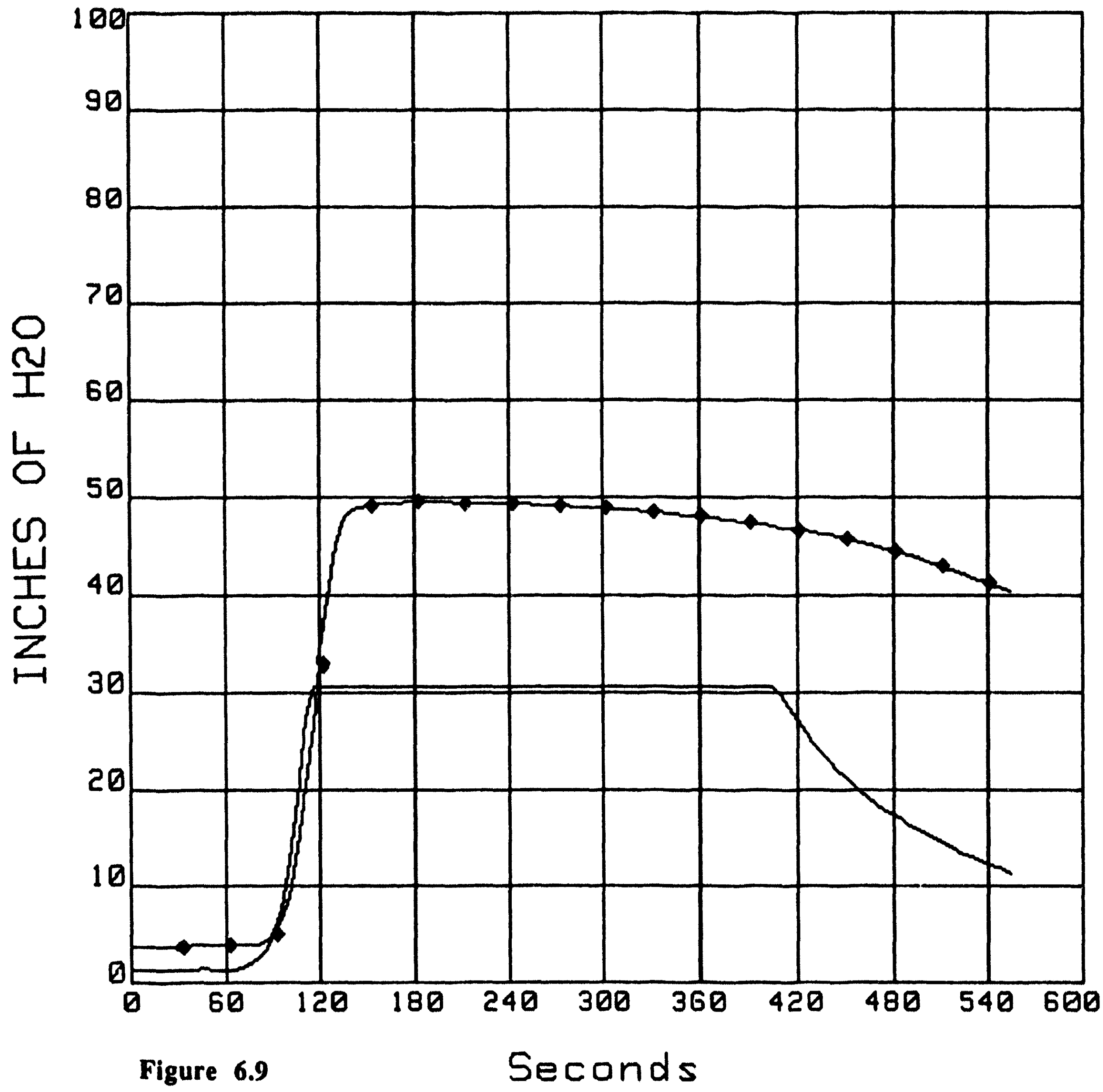


Figure 6.9

Date: 15 Jul 19 Time: 14:35:45

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL6.0	CH-32	CELL MANIFOLD TC	Degrees Celsius	300
◆ ORNL6.0	CH-34	CEL EXH DUCT TC	Degrees Celsius	300
× ORNL6.0	CH-35	EXH/MAKEUP NODE TC	Degrees Celsius	300
● ORNL6.0	CH-36	TC BEFORE PREFILTER	Degrees Celsius	300
■ ORNL6.0	CH-37	TC BEFORE HEPA	Degrees Celsius	300

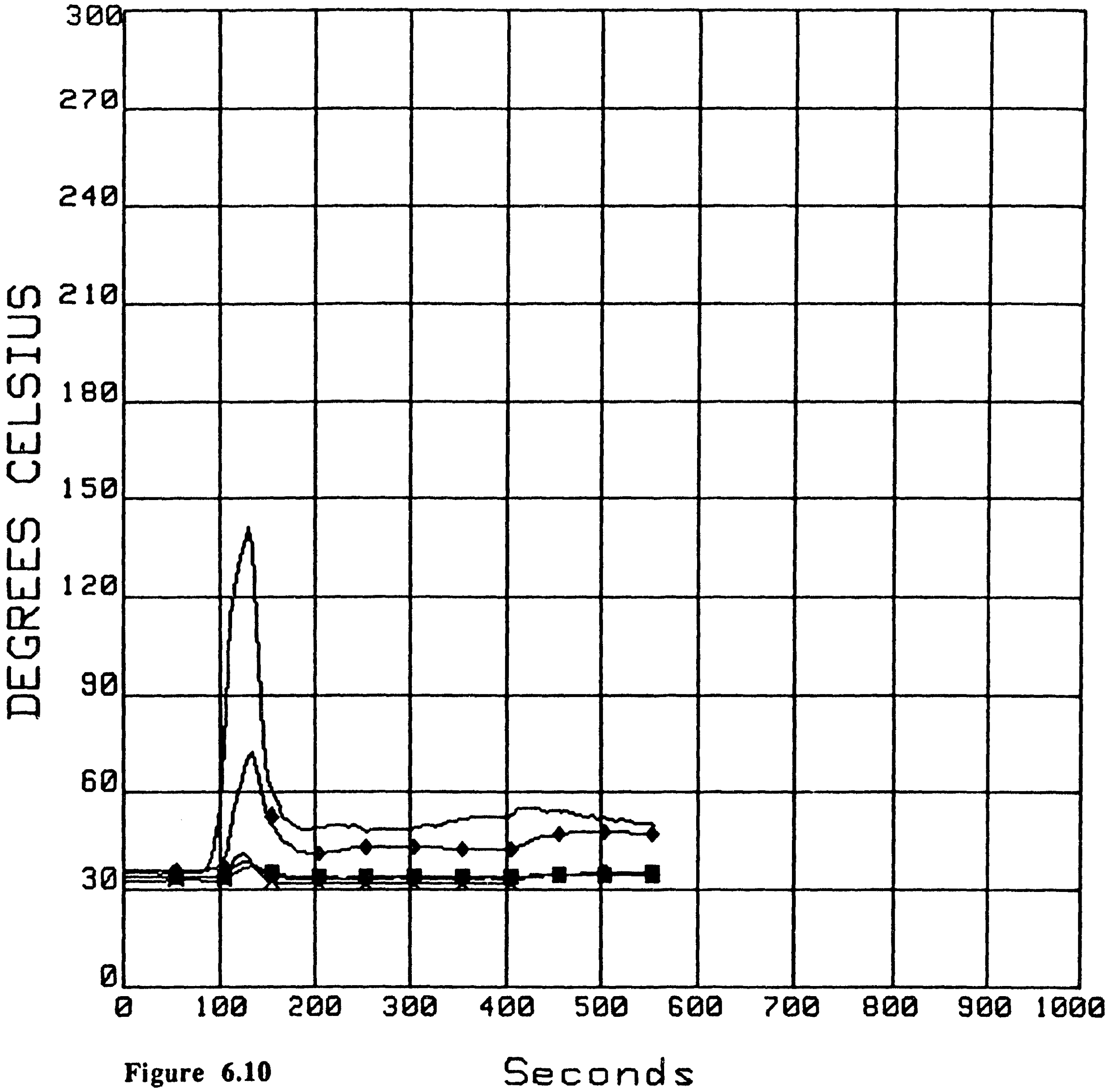


Figure 6.10

Date: 15 Jul 19 Time: 14:35:45

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL6.0	CH-84	O2 12' UP	% O2	25
◆ ORNL6.0	CH-85	CO2 12' UP	% CO2	12
× ORNL6.0	CH-86	CO 12' UP	% CO	1.5
● ORNL6.0	CH-87	HC 12'UP	PPM (=CH4)	25000

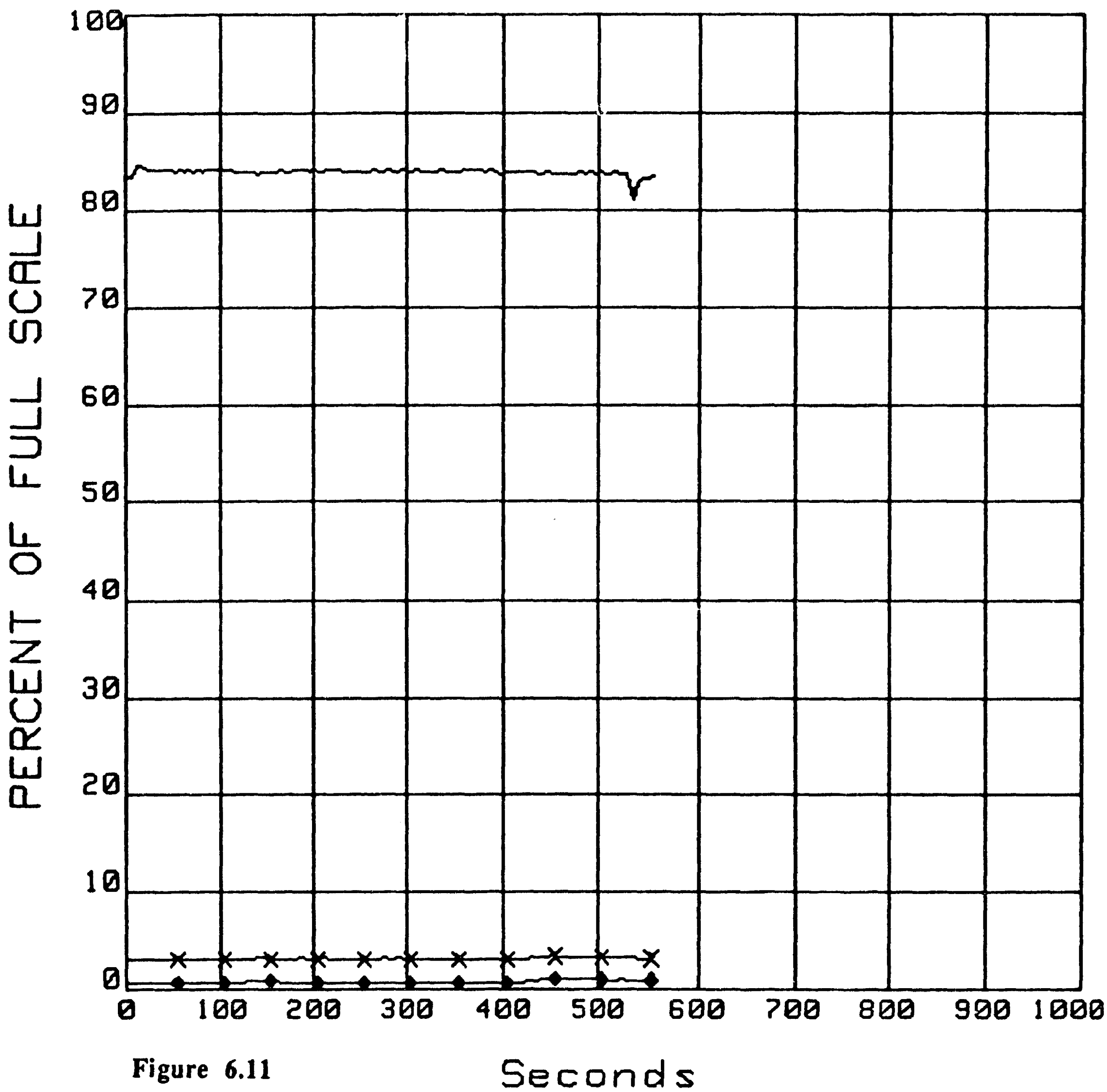


Figure 6.11

Date: 15 Jul 19 Time: 14:35:45

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL6.0	CH-88	O2 Duct Node	% O2	25
◆ ORNL6.0	CH-89	CO2 Duct Node	% CO2	12
× ORNL6.0	CH-90	CO Duct Node	% CO	1.5
● ORNL6.0	CH-91	HC Duct Node	PPM (=CH4)	25000

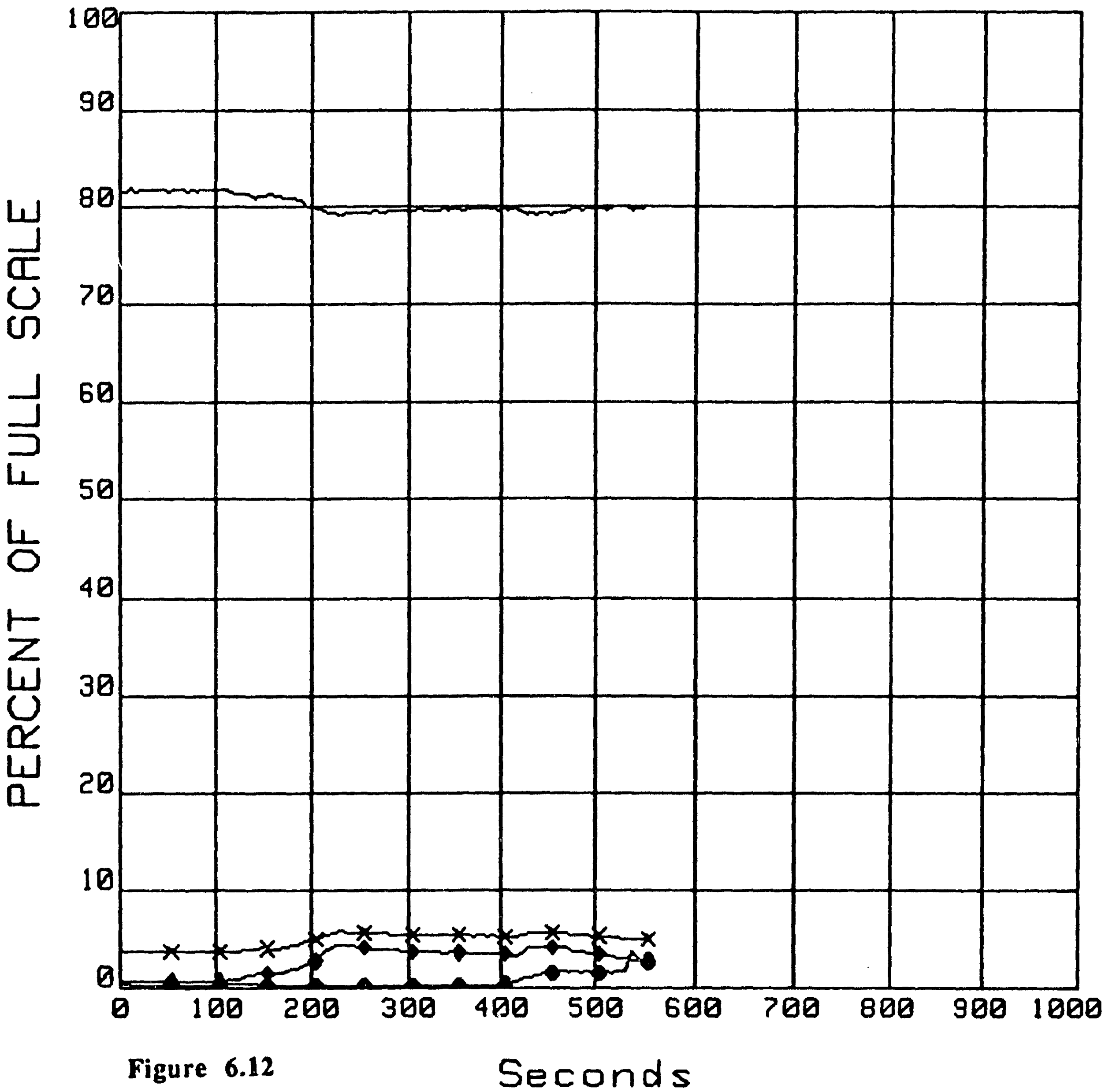


Figure 6.12

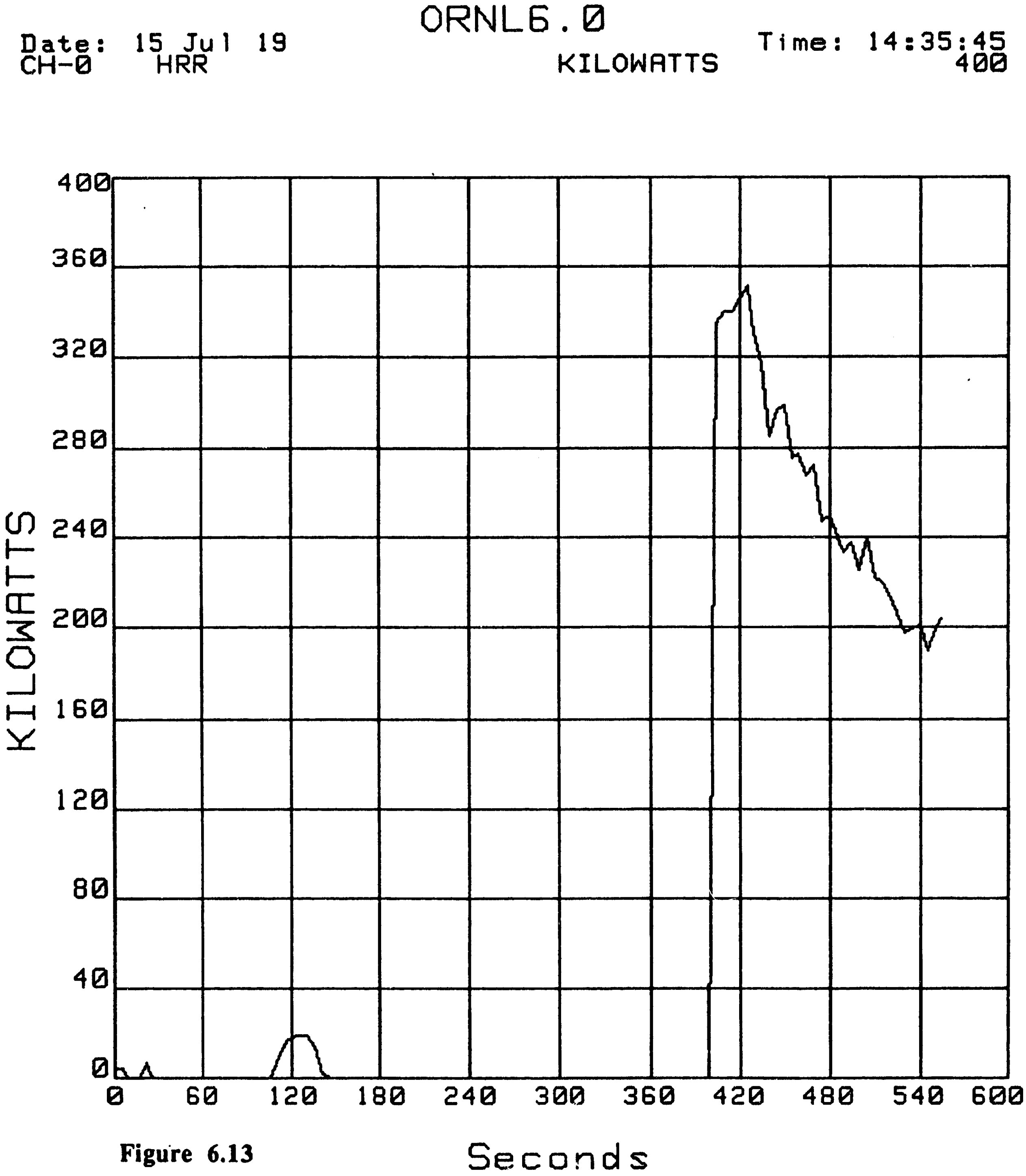


Figure 6.13

lo. of channels=73

Date: 15 Jul 19 Time: 14:35:45

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL6.0	CH-102	Inlet A/F (TFM)	CFM	2000
◆ ORNL6.0	CH-80	02 6' UP	% 02	25
× ORNL6.0	CH-84	02 12' UP	% 02	25
● ORNL6.0	CH-88	02 Duct Node	% 02	25

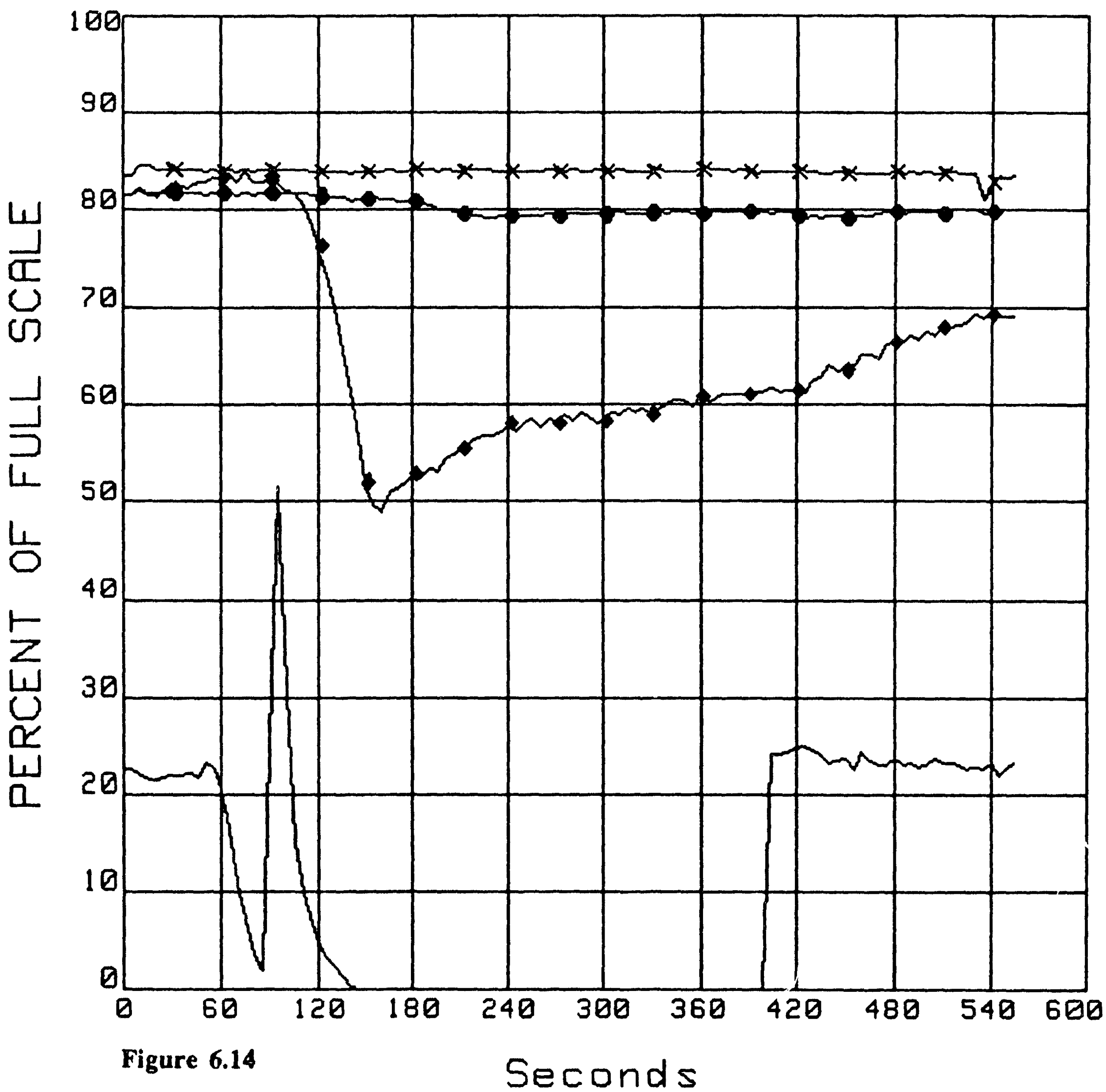


Figure 6.14

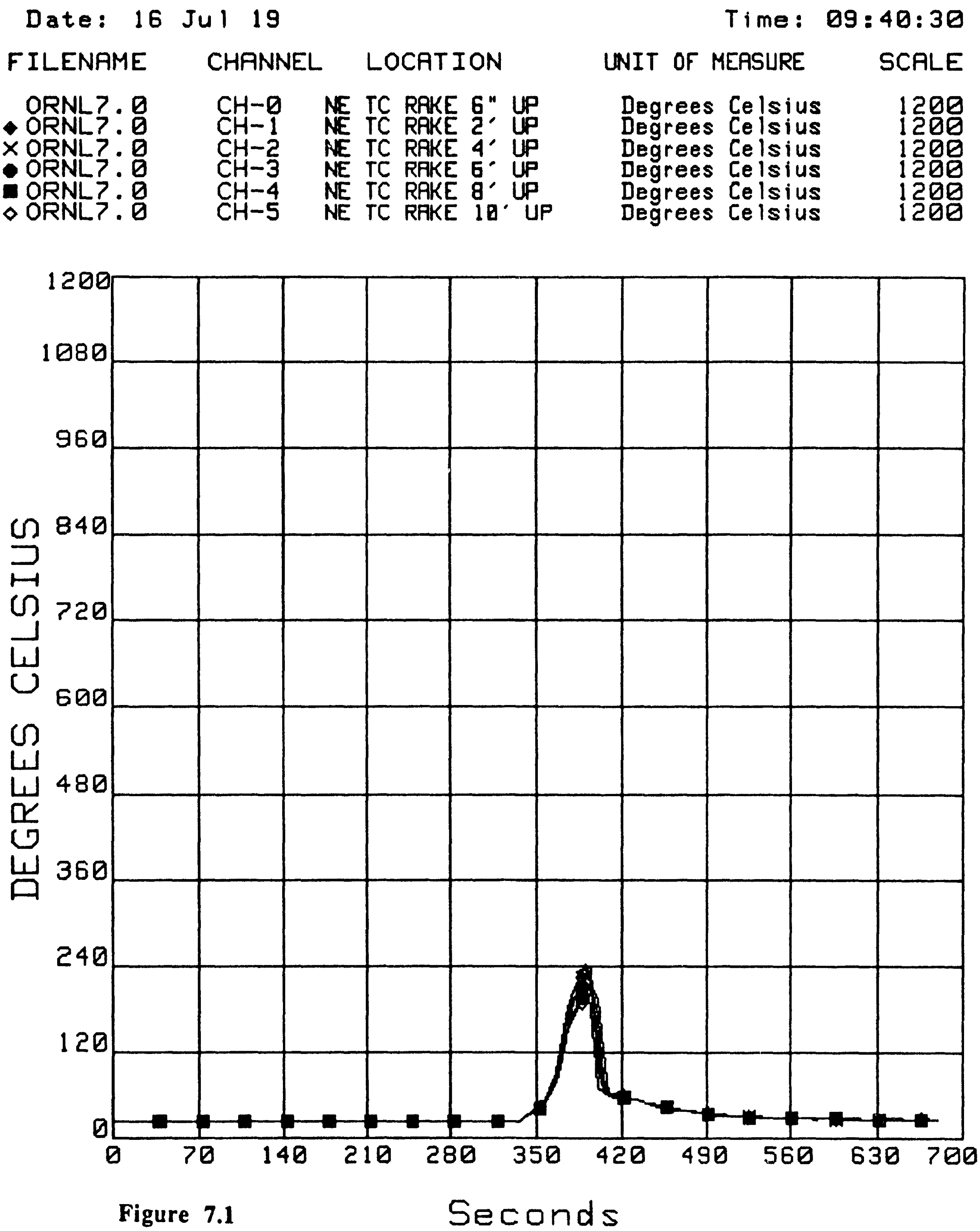

Date: 16 Jul 19
Time: 09:40:30
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL7.0 CH-0 NE TC RAKE 6" UP Degrees Celsius 1200
ORNL7.0 CH-1 NE TC RAKE 2' UP Degrees Celsius 1200
ORNL7.0 CH-2 NE TC RAKE 4' UP Degrees Celsius 1200
ORNL7.0 CH-3 NE TC RAKE 6' UP Degrees Celsius 1200
ORNL7.0 CH-4 NE TC RAKE 8' UP Degrees Celsius 1200
ORNL7.0 CH-5 NE TC RAKE 10' UP Degrees Celsius 1200
DEGREES CELSIUS
1200
1080
960
840
720
600
480
360
240
120
0
0 70 140 210 280 350 420 490 560 630 700
Seconds

Figure 7.1

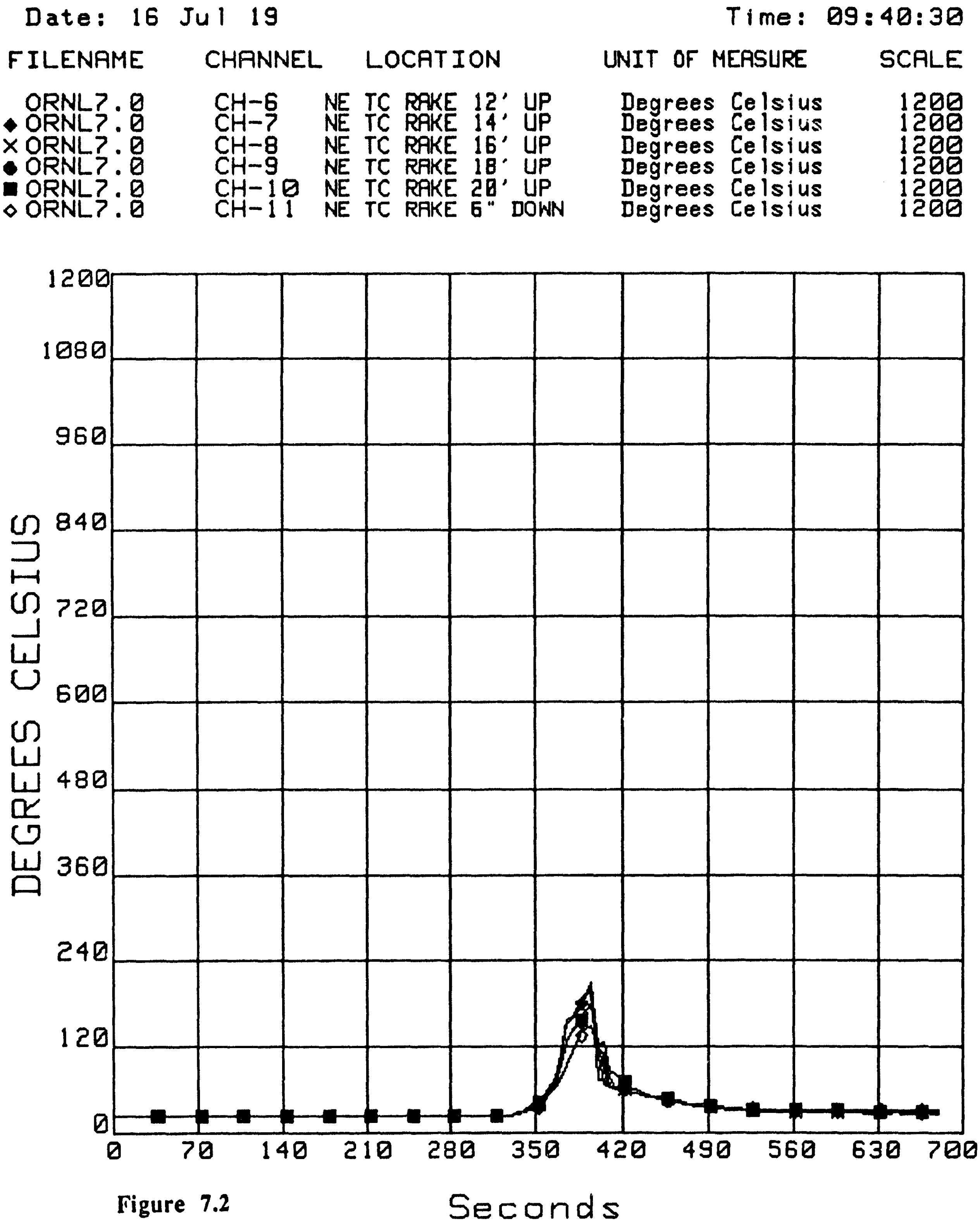

Date: 16 Jul 19
Time: 09:40:30
FILENAME
CHANNEL
LOCATION
UNIT OF MEASURE
SCALE
ORNL7.0 CH-6 NE TC RAKE 12' UP Degrees Celsius 1200
◆ ORNL7.0 CH-7 NE TC RAKE 14' UP Degrees Celsius 1200
× ORNL7.0 CH-8 NE TC RAKE 16' UP Degrees Celsius 1200
● ORNL7.0 CH-9 NE TC RAKE 18' UP Degrees Celsius 1200
■ ORNL7.0 CH-10 NE TC RAKE 20' UP Degrees Celsius 1200
◇ ORNL7.0 CH-11 NE TC RAKE 6" DOWN Degrees Celsius 1200
1200
1080
960
840
720
600
480
360
240
120
0
DEGREES CELSIUS
0
70
140
210
280
350
420
490
560
630
700
Seconds

Figure 7.2

Date: 16 Jul 19 Time: 09:40:30

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL7.0	CH-20	So TC RAKE 6" UP	Degrees Celsius	1200
◆ ORNL7.0	CH-21	So TC RAKE 2' UP	Degrees Celsius	1200
× ORNL7.0	CH-22	So TC RAKE 4' UP	Degrees Celsius	1200
● ORNL7.0	CH-23	So TC RAKE 6' UP	Degrees Celsius	1200

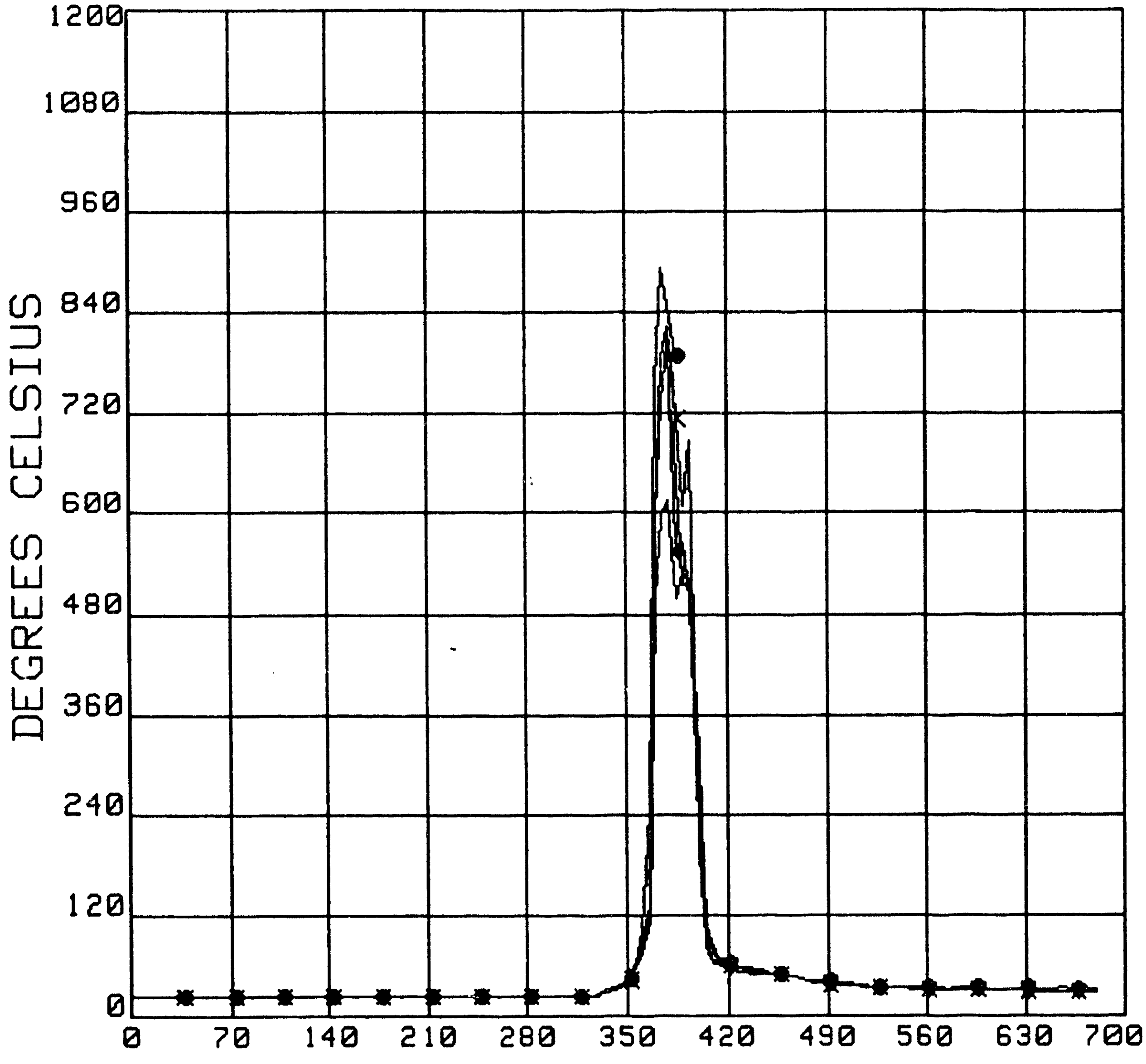


Figure 7.3

Date: 16 Jul 19 Time: 09:40:30

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL7.0	CH-27	TOP So WINDOW TC	Degrees Celsius	1200
◆ ORNL7.0	CH-28	TOP No WINDOW TC	Degrees Celsius	1200
× ORNL7.0	CH-29	BOTTOM So WINDOW TC	Degrees Celsius	1200
● ORNL7.0	CH-30	BOTTOM No WINDOW TC	Degrees Celsius	1200

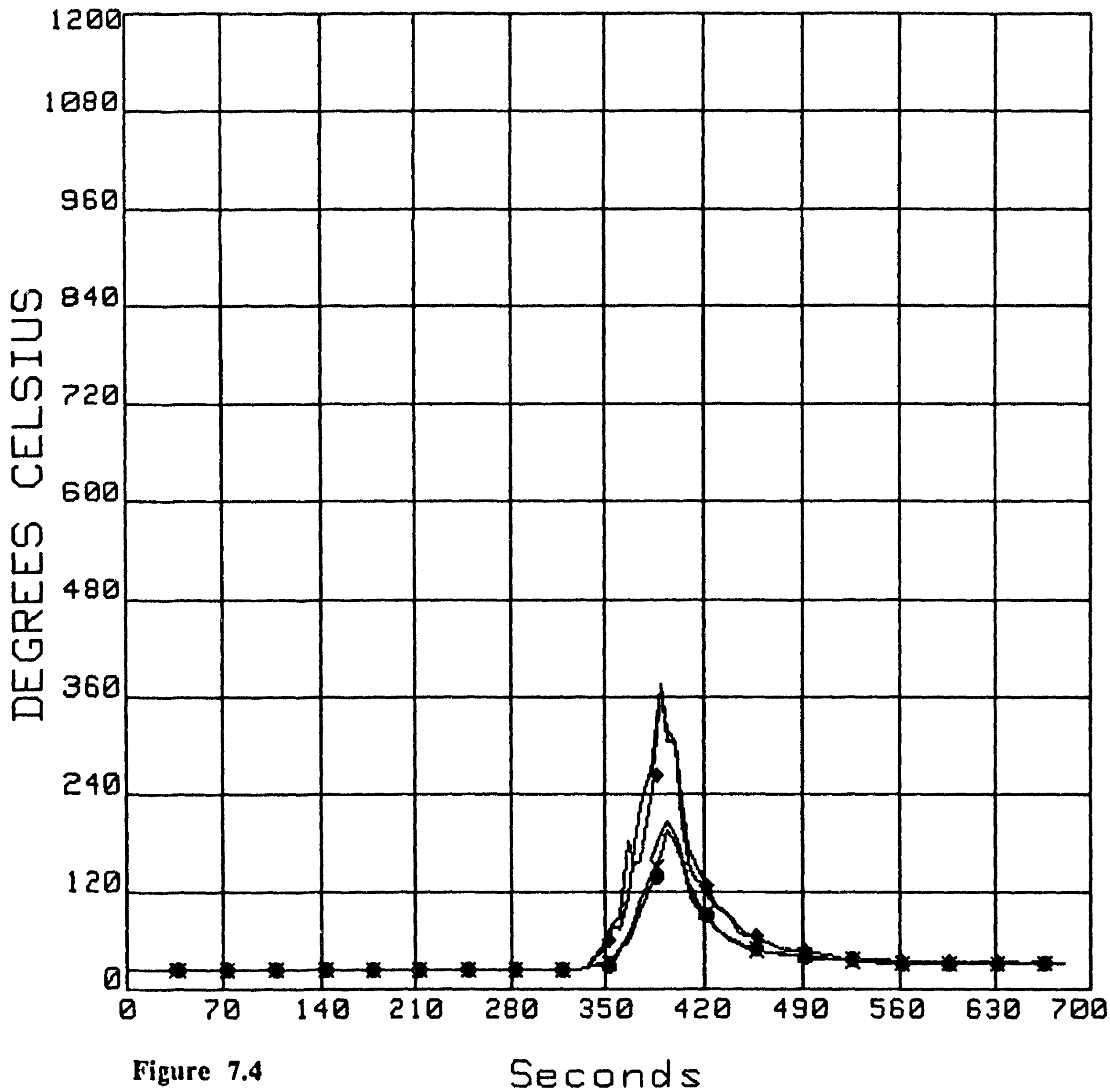


Figure 7.4

Date: 16 Jul 19 Time: 09:40:30

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL7.0	CH-80	O2 6′ UP	% O2	25
◆ ORNL7.0	CH-81	CO2 6′ UP	% CO2	12
× ORNL7.0	CH-82	CO 6′ UP	% CO	1.5
● ORNL7.0	CH-83	HC 6′ UP	PPM (=CH4)	25000

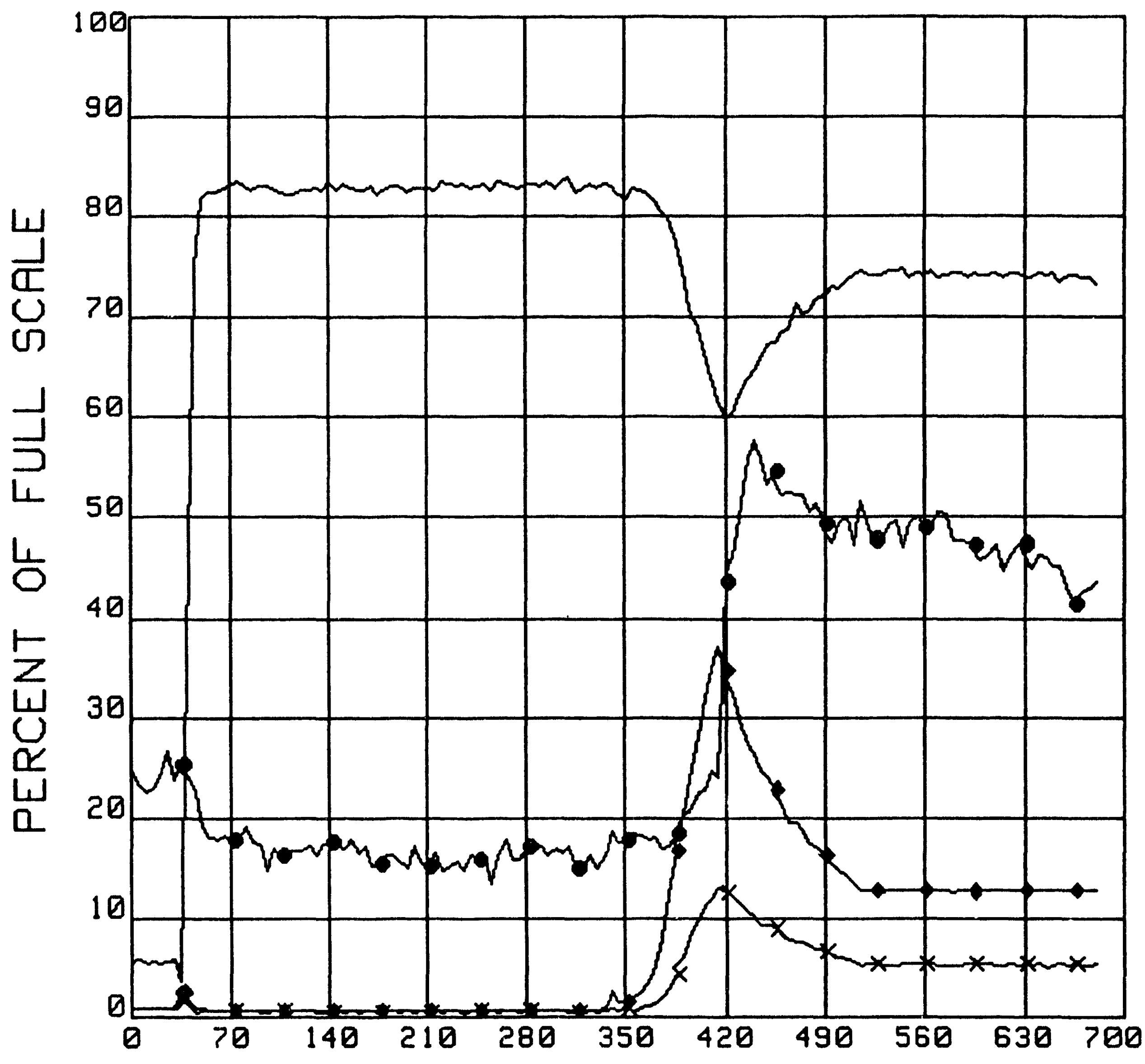


Figure 7.5

Date: 16 Jul 19 Time: 09:40:30

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL7.0	CH-95	Near Cell	% Transmittance	100
◆ ORNL7.0	CH-96	Before Filters	% Transmittance	100

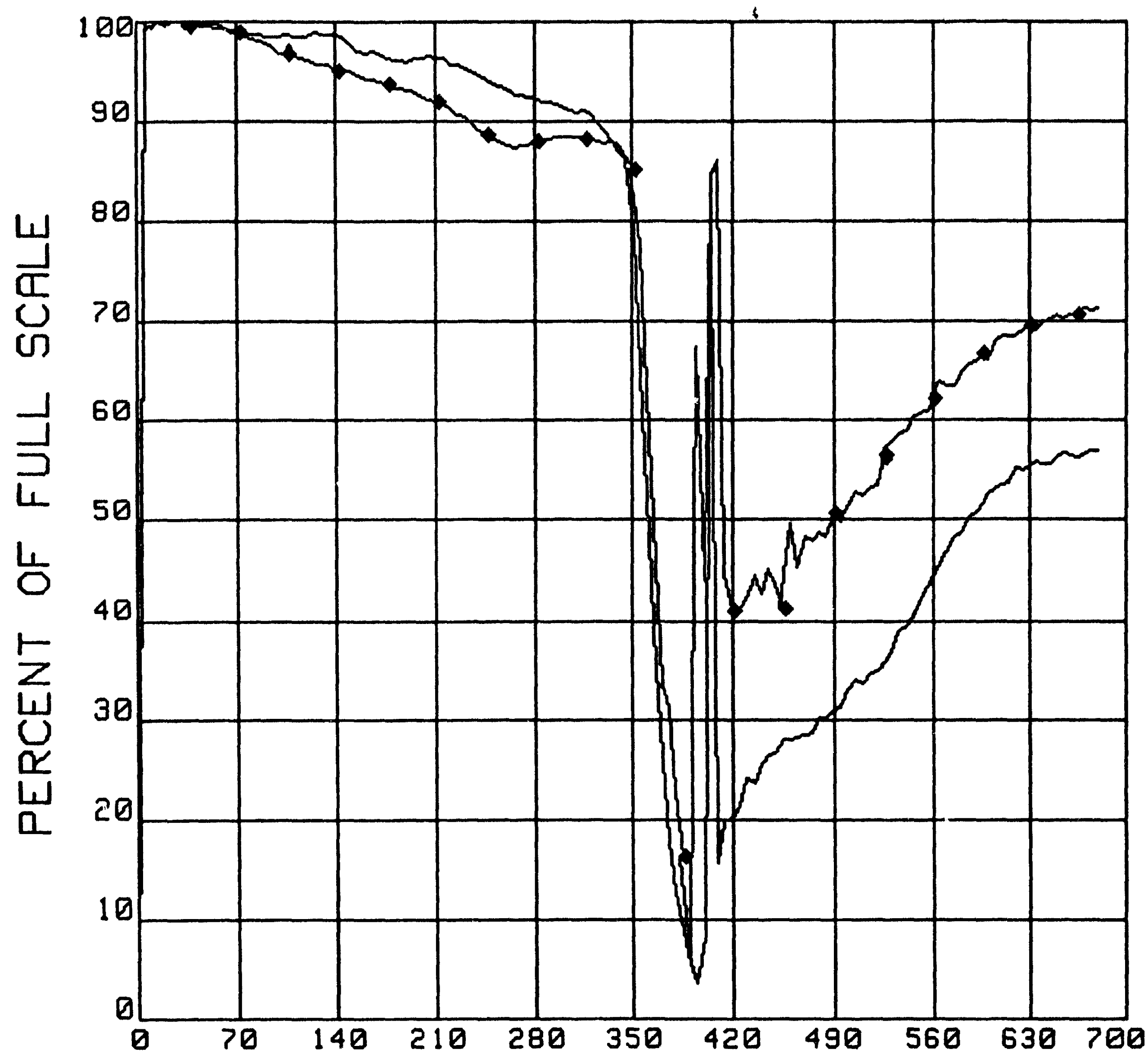


Figure 7.6

Date: 16 Jul 19 Time: 09:40:30

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL7.0	CH-102	Inlet A/F (TFM)	CFM	5000
◆ ORNL7.0	CH-104	Exit A/F (Pitot)	CFM	5000
× ORNL7.0	CH-105	Exit A/F (TFM)	CFM	5000

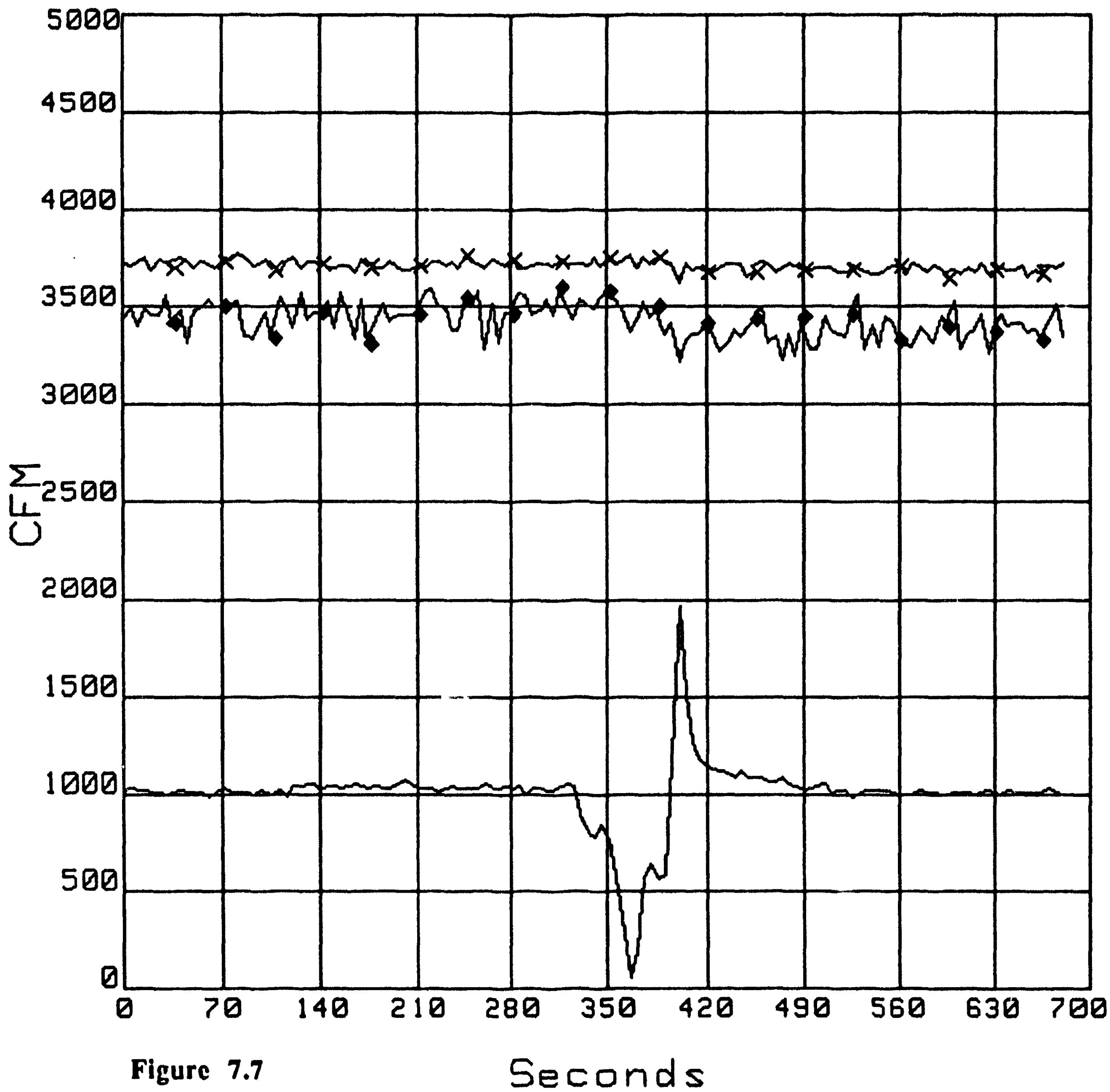


Figure 7.7

Date: 16 Jul 19 Time: 09:40:30

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL7.0	CH-109	Delta P HEPA	INCHES H20	5
◆ ORNL7.0	CH-110	Delta P PreFilter	INCHES H20	5

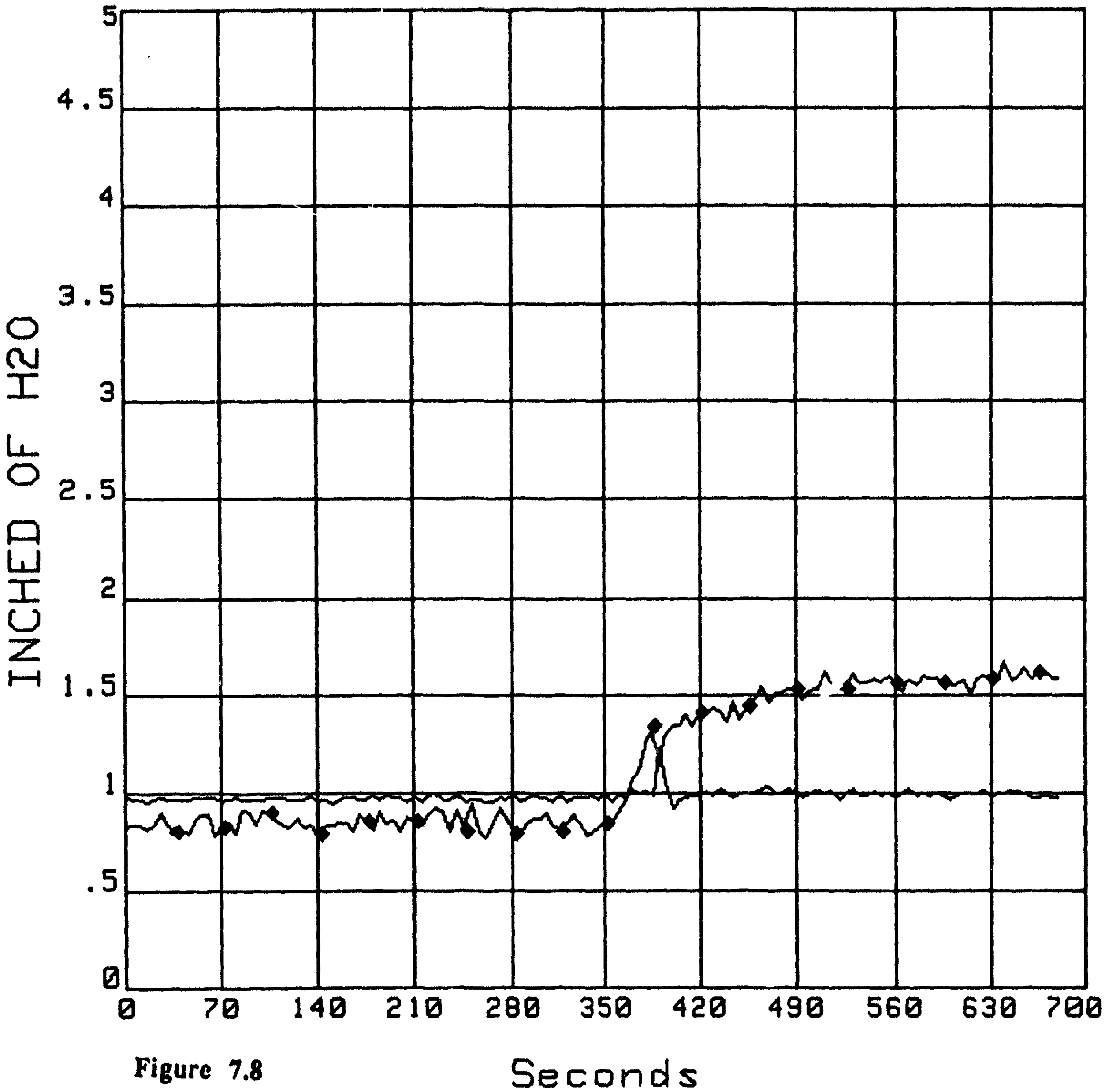


Figure 7.8

Date: 16 Jul 19 Time: 09:40:30

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL7.0	CH-112	Heat Sensor 22'side	INCHES H2O	100
◆ ORNL7.0	CH-113	Heat Sensor 13' side	Inches H2O	100

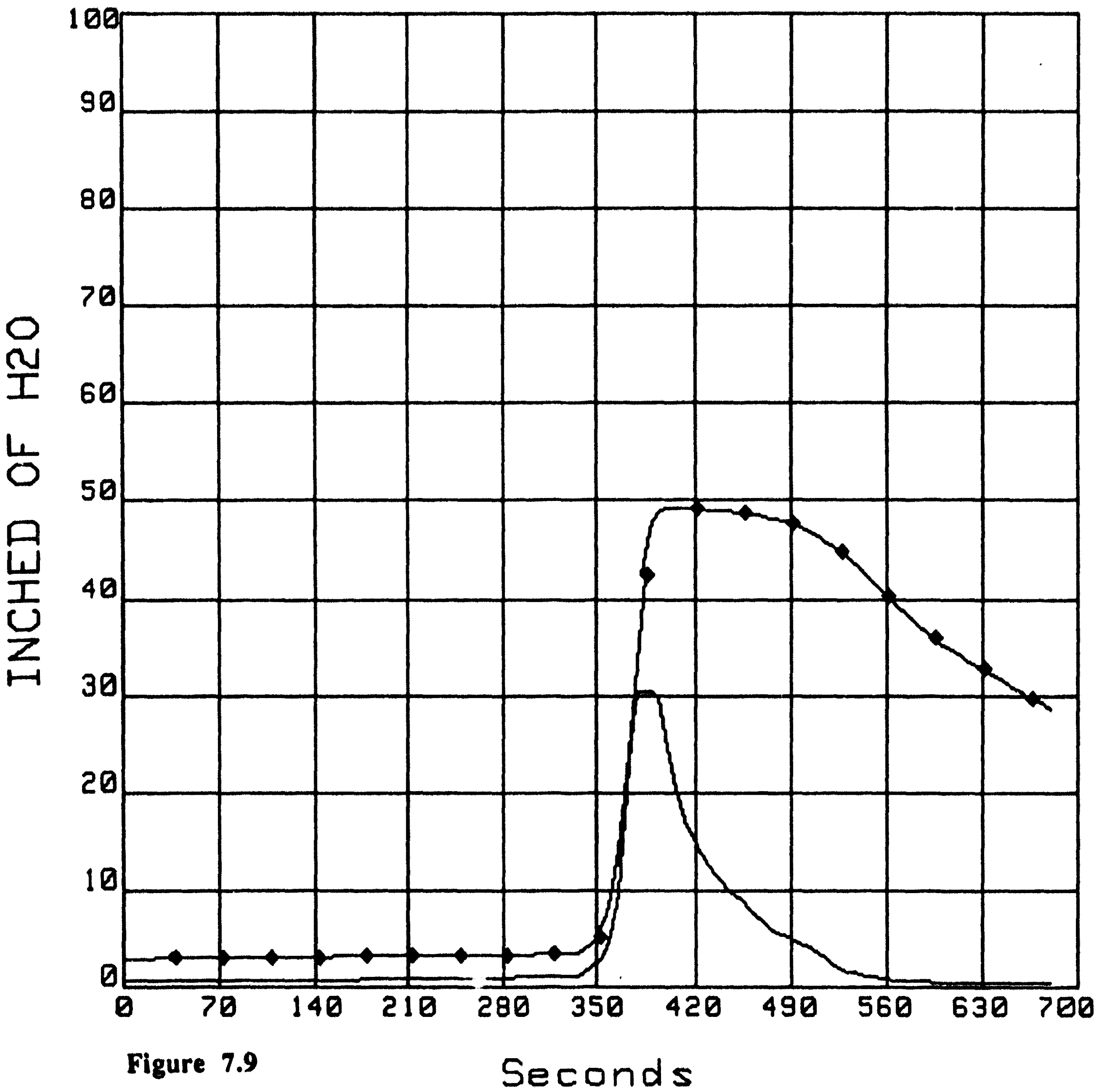
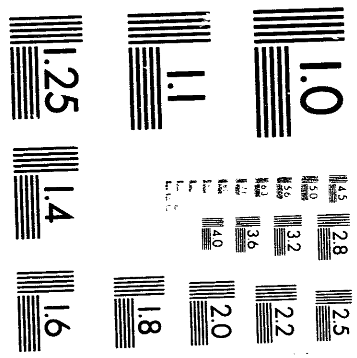


Figure 7.9


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3

Date: 16 Jul 19 Time: 09:40:30

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL7.0	CH-32	CELL MANIFOLD TC	Degrees Celsius	300
◆ ORNL7.0	CH-34	CEL EXH DUCT TC	Degrees Celsius	300
× ORNL7.0	CH-35	EXH/MAKEUP NODE TC	Degrees Celsius	300
● ORNL7.0	CH-36	TC BEFORE PREFILTER	Degrees Celsius	300
■ ORNL7.0	CH-37	TC BEFORE HEPA	Degrees Celsius	300

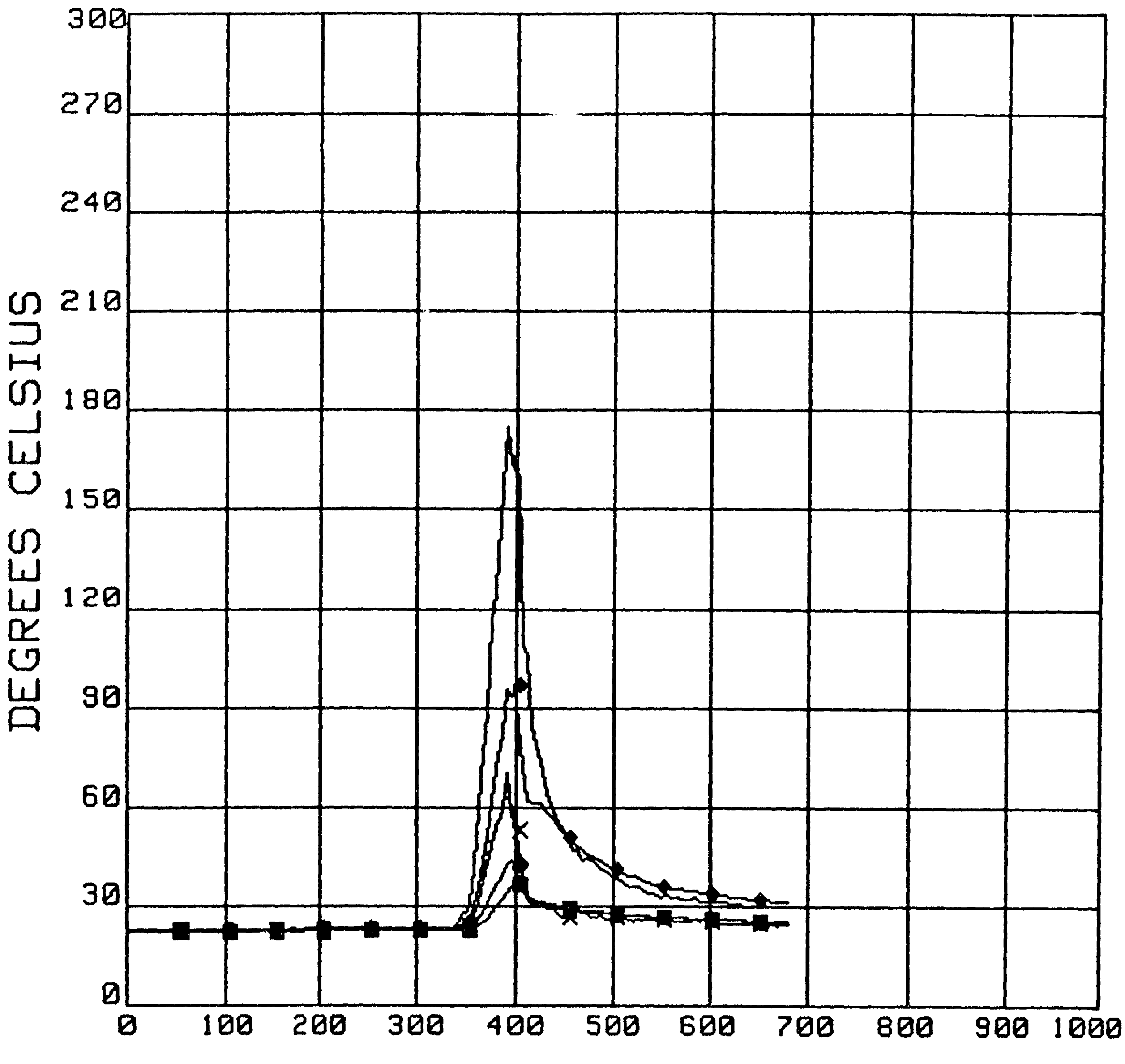


Figure 7.10

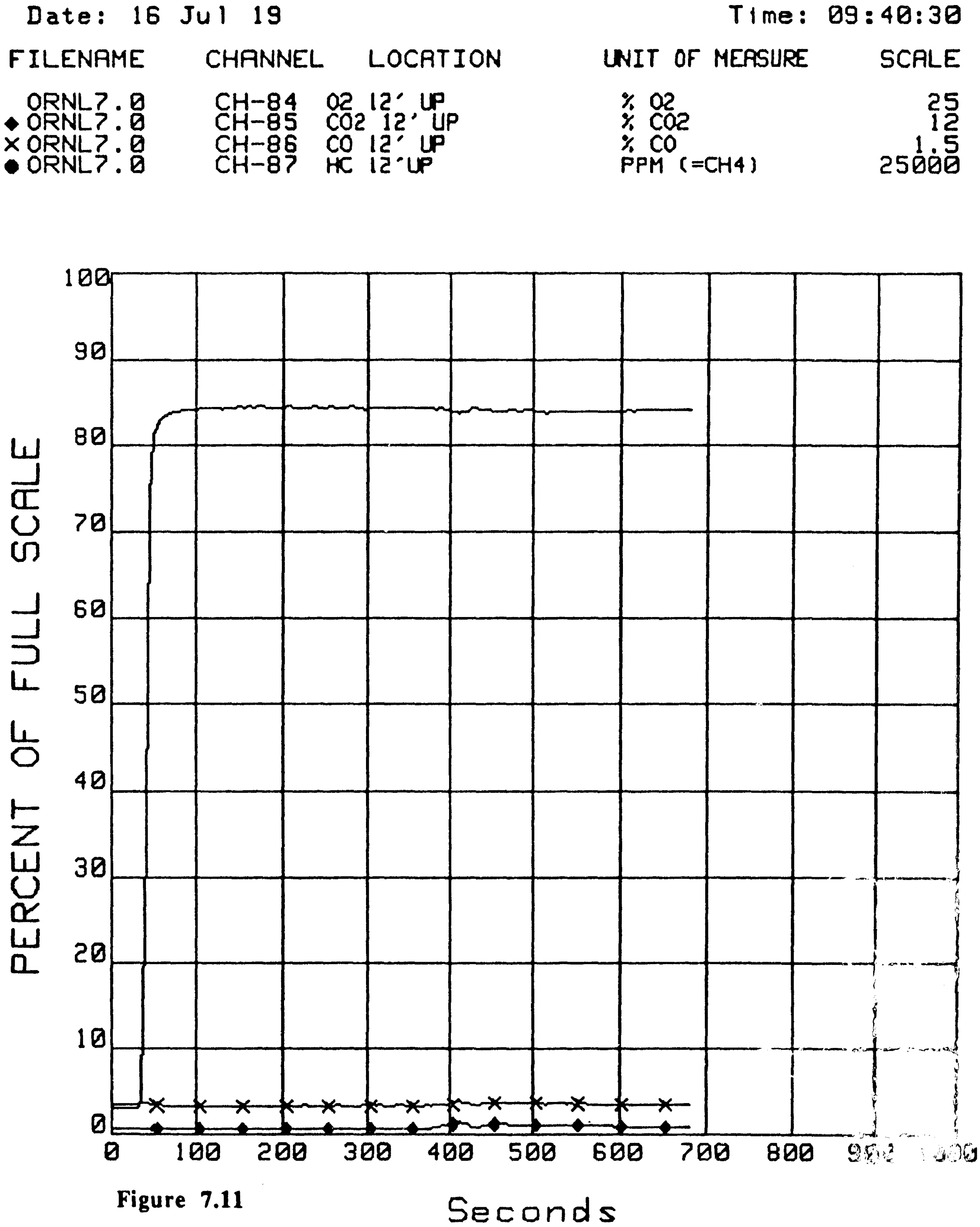

Date: 16 Jul 19
Time: 09:40:30
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL7.0 CH-84 O2 12' UP % O2 25
◆ ORNL7.0 CH-85 CO2 12' UP % CO2 12
× ORNL7.0 CH-86 CO 12' UP % CO 1.5
● ORNL7.0 CH-87 HC 12'UP PPM (=CH4) 25000
PERCENT OF FULL SCALE
0 10 20 30 40 50 60 70 80 90 100
0 100 200 300 400 500 600 700 800 900 1000
Seconds

Figure 7.11

Date: 16 Jul 19 Time: 09:40:30

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL7.0	CH-88	O2 Duct Node	% O2	25
◆ ORNL7.0	CH-89	CO2 Duct Node	% CO2	12
× ORNL7.0	CH-90	CO Duct Node	% CO	1.5
● ORNL7.0	CH-91	HC Duct Node	PPM (=CH4)	25000

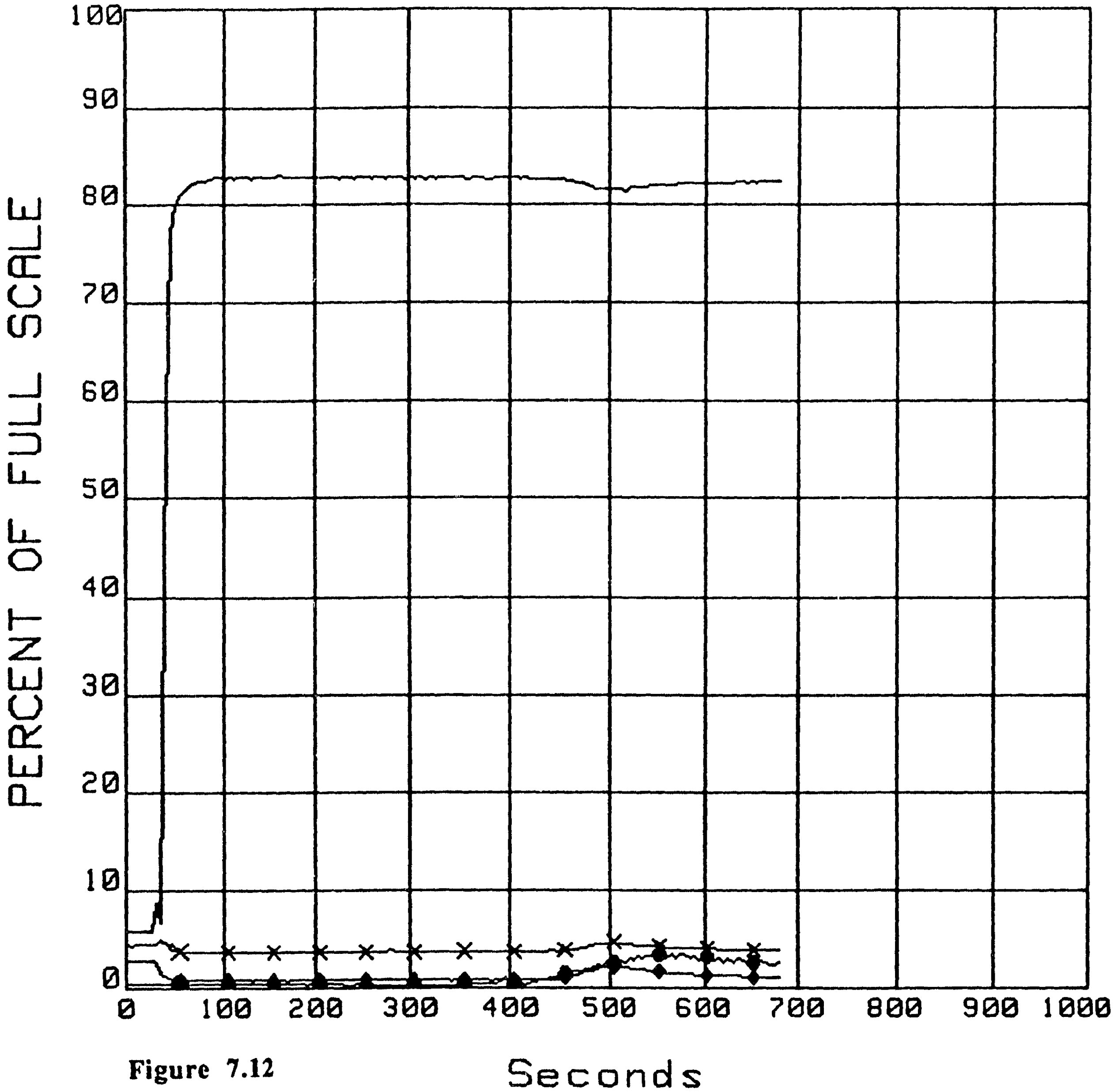
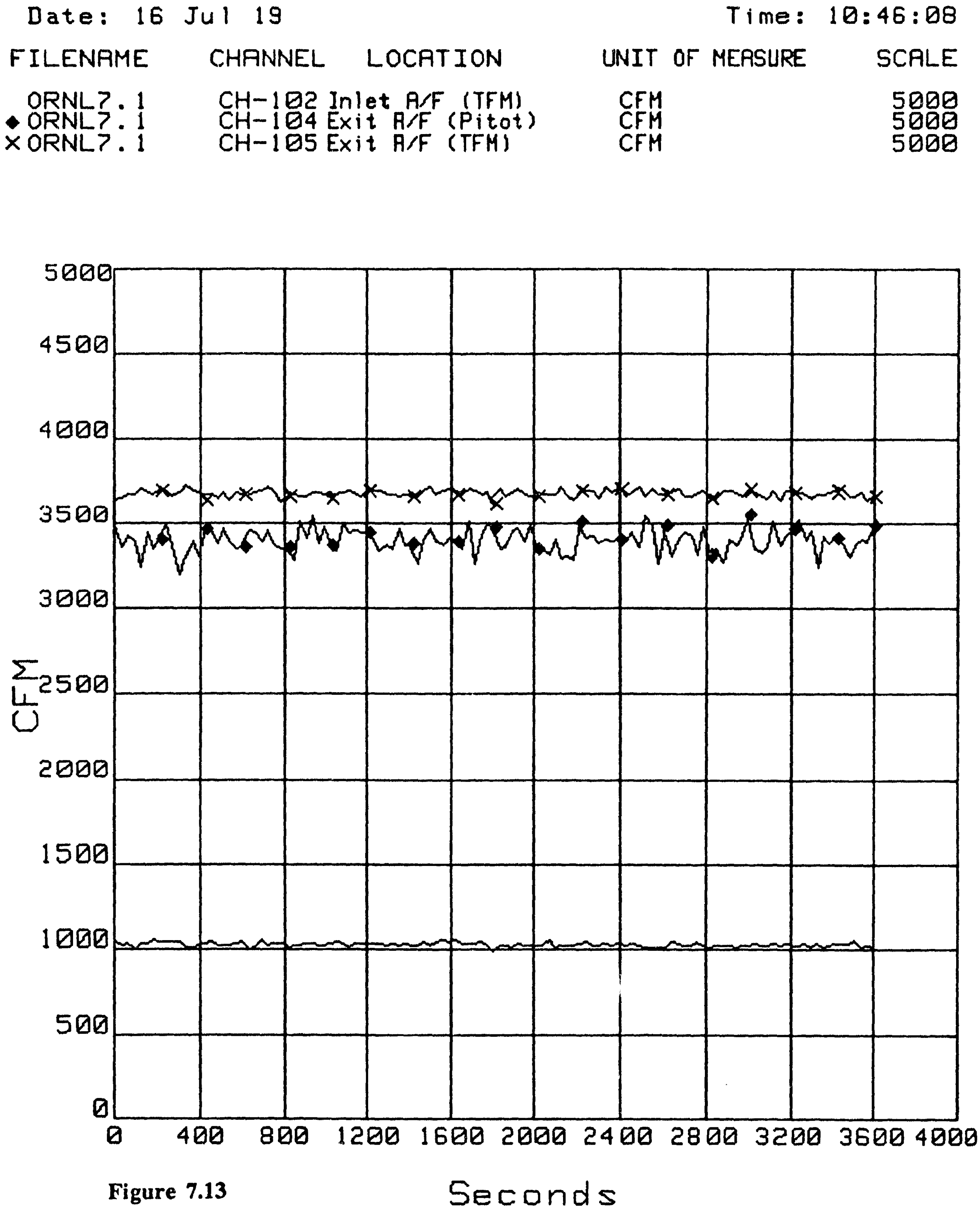


Figure 7.12



Date: 16 Jul 19
Time: 10:46:08
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL7.1 CH-102 Inlet A/F (TFM) CFM 5000
◆ORNL7.1 CH-104 Exit A/F (Pitot) CFM 5000
×ORNL7.1 CH-105 Exit A/F (TFM) CFM 5000
CFM
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0 400 800 1200 1600 2000 2400 2800 3200 3600 4000
Seconds

Figure 7.13

Date: 16 Jul 19 Time: 10:46:08

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL7.1	CH-109	Delta P HEPA	INCHES H2O	5
◆ ORNL7.1	CH-110	Delta P PreFilter	INCHES H2O	5

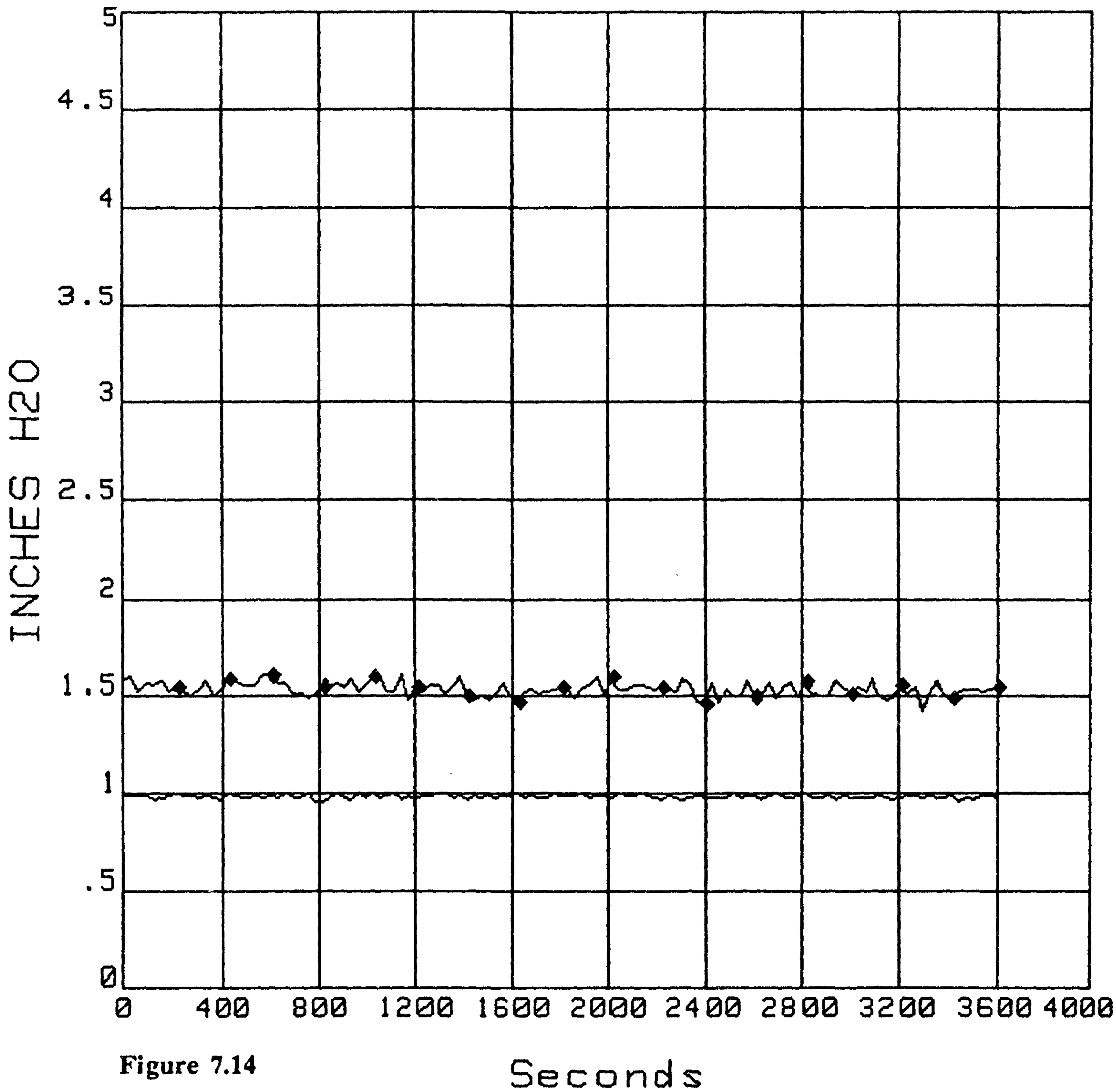
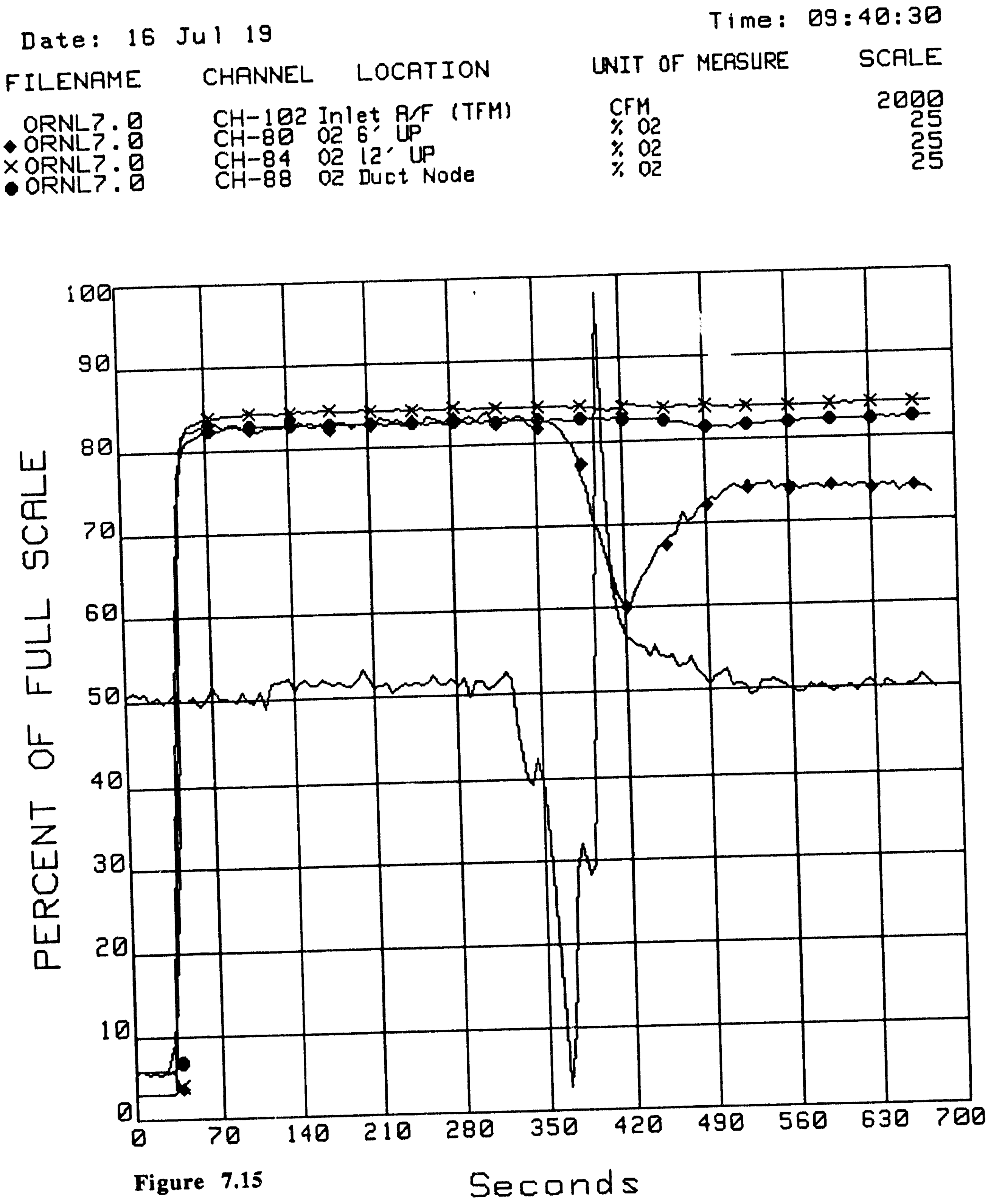


Figure 7.14



Date: 16 Jul 19
Time: 09:40:30
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL7.0 CH-102 Inlet A/F (TFM) CFM 2000
◆ORNL7.0 CH-80 O2 6' UP % O2 25
×ORNL7.0 CH-84 O2 12' UP % O2 25
●ORNL7.0 CH-88 O2 Duct Node % O2 25
PERCENT OF FULL SCALE
100
90
80
70
60
50
40
30
20
10
0
0
70
140
210
280
350
420
490
560
630
700
Seconds

Figure 7.15

Date: 16 Jul 19 Time: 14:25:25

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL8.0	CH-0	NE TC RAKE 6" UP	Degrees Celsius	1200
◆ ORNL8.0	CH-1	NE TC RAKE 2′ UP	Degrees Celsius	1200
× ORNL8.0	CH-2	NE TC RAKE 4′ UP	Degrees Celsius	1200
● ORNL8.0	CH-3	NE TC RAKE 6′ UP	Degrees Celsius	1200
■ ORNL8.0	CH-4	NE TC RAKE 8′ UP	Degrees Celsius	1200
◇ ORNL8.0	CH-5	NE TC RAKE 10′ UP	Degrees Celsius	1200

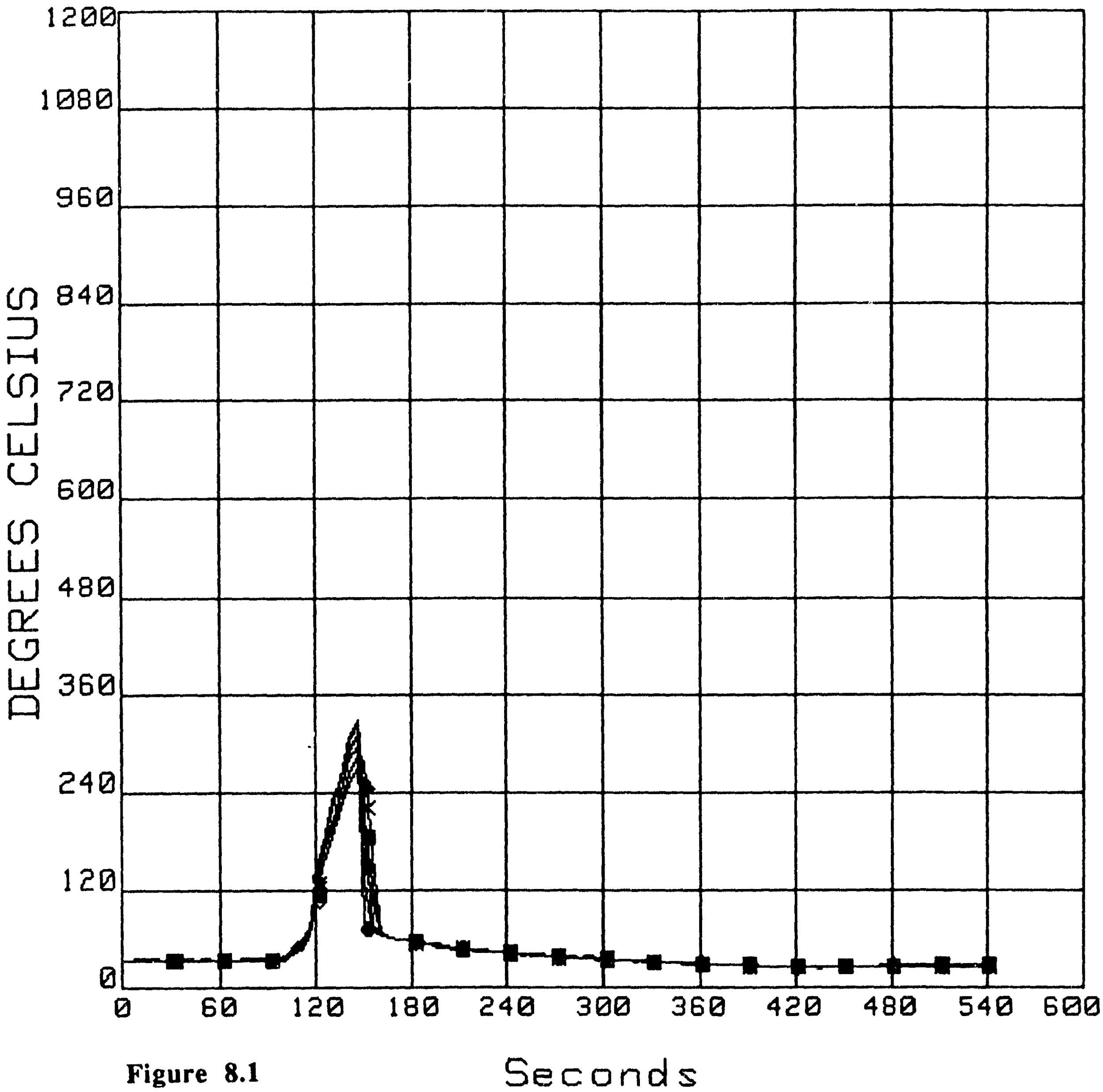


Figure 8.1

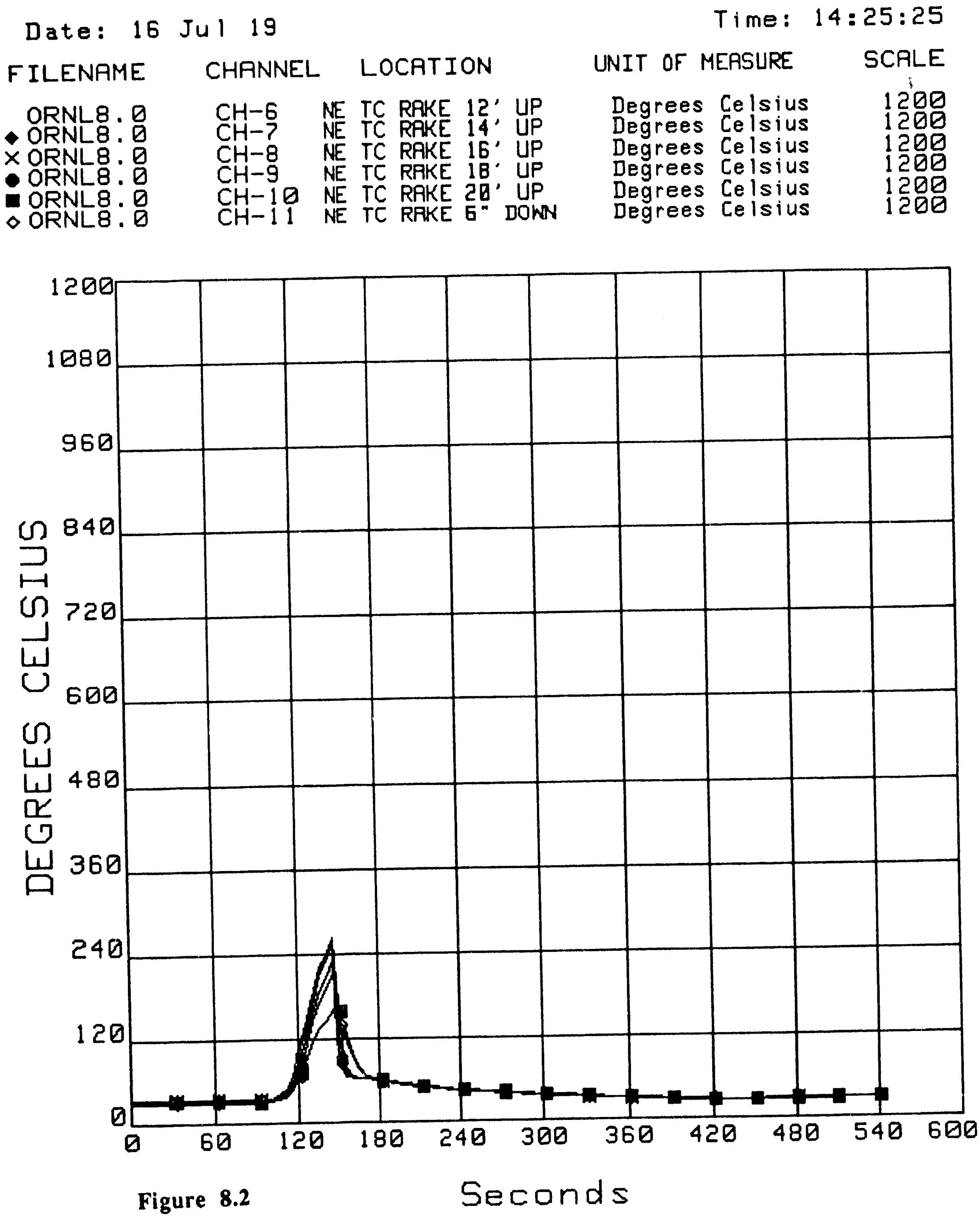

Date: 16 Jul 19
Time: 14:25:25
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL8.0 CH-6 NE TC RAKE 12' UP Degrees Celsius 1200
ORNL8.0 CH-7 NE TC RAKE 14' UP Degrees Celsius 1200
ORNL8.0 CH-8 NE TC RAKE 16' UP Degrees Celsius 1200
ORNL8.0 CH-9 NE TC RAKE 18' UP Degrees Celsius 1200
ORNL8.0 CH-10 NE TC RAKE 20' UP Degrees Celsius 1200
ORNL8.0 CH-11 NE TC RAKE 6" DOWN Degrees Celsius 1200
DEGREES CELSIUS
1200
1080
960
840
720
600
480
360
240
120
0
0
60
120
180
240
300
360
420
480
540
600
Seconds

Figure 8.2

Date: 16 Jul 19 Time: 14:25:25

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL8.0	CH-20	So TC RAKE 6" UP	Degrees Celsius	1200
◆ ORNL8.0	CH-21	So TC RAKE 2′ UP	Degrees Celsius	1200
× ORNL8.0	CH-22	So TC RAKE 4′ UP	Degrees Celsius	1200
● ORNL8.0	CH-23	So TC RAKE 6′ UP	Degrees Celsius	1200

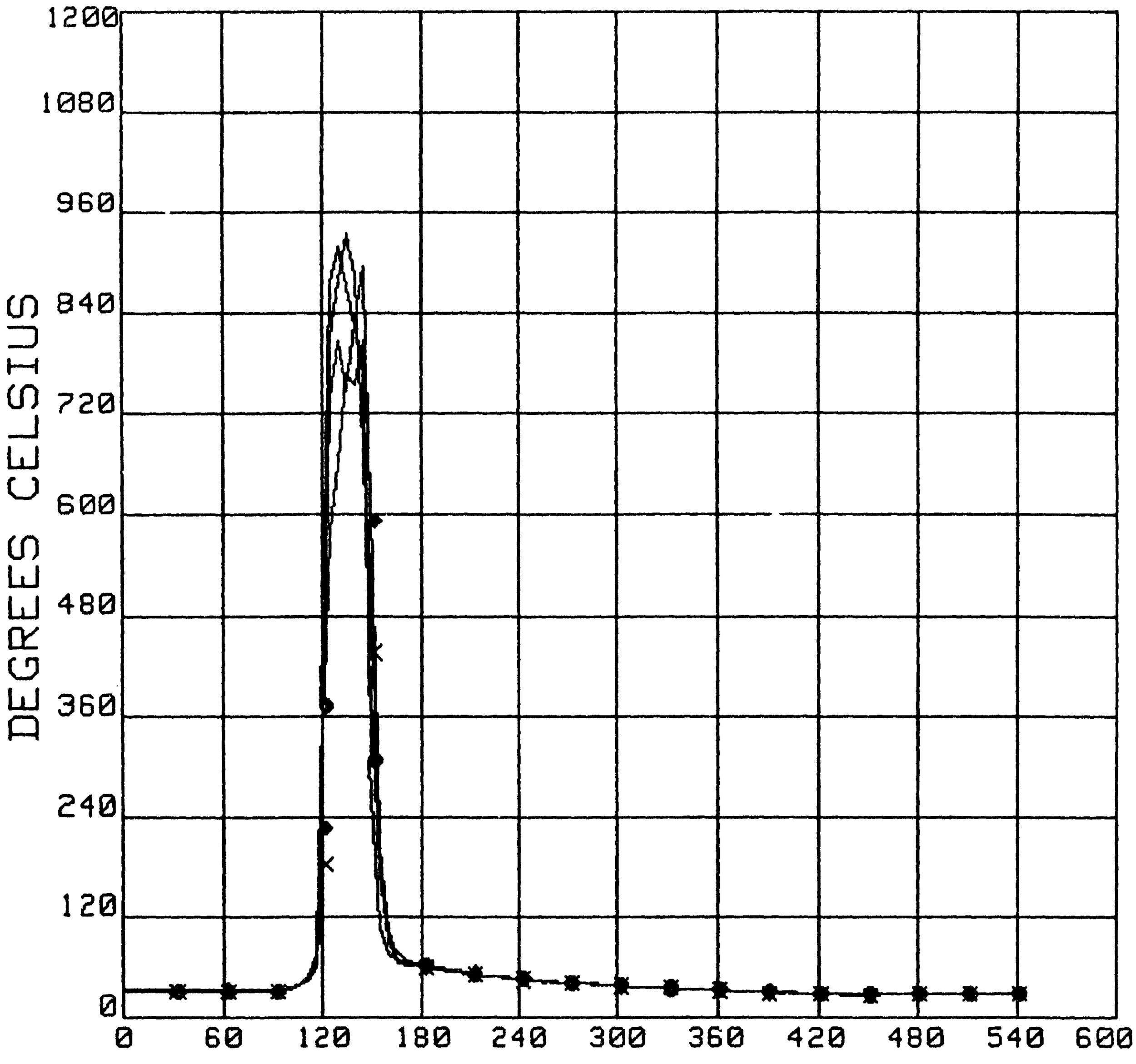


Figure 8.3

Date: 16 Jul 19 Time: 14:25:25

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL8.0	CH-27	TOP So WINDOW TC	Degrees Celsius	1200
◆ ORNL8.0	CH-28	TOP No WINDOW TC	Degrees Celsius	1200
× ORNL8.0	CH-29	BOTTOM So WINDOW TC	Degrees Celsius	1200
● ORNL8.0	CH-30	BOTTOM No WINDOW TC	Degrees Celsius	1200

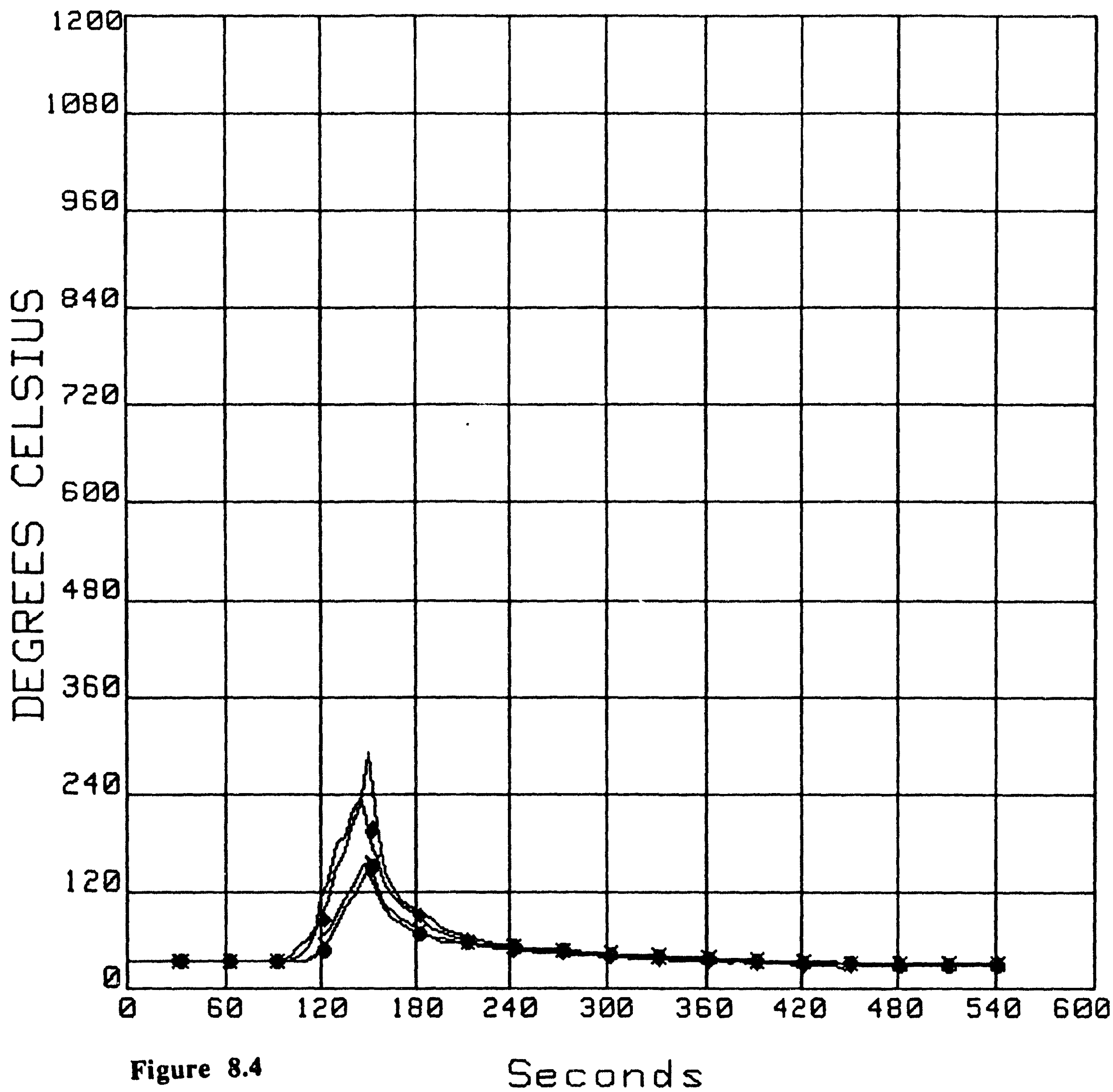


Figure 8.4

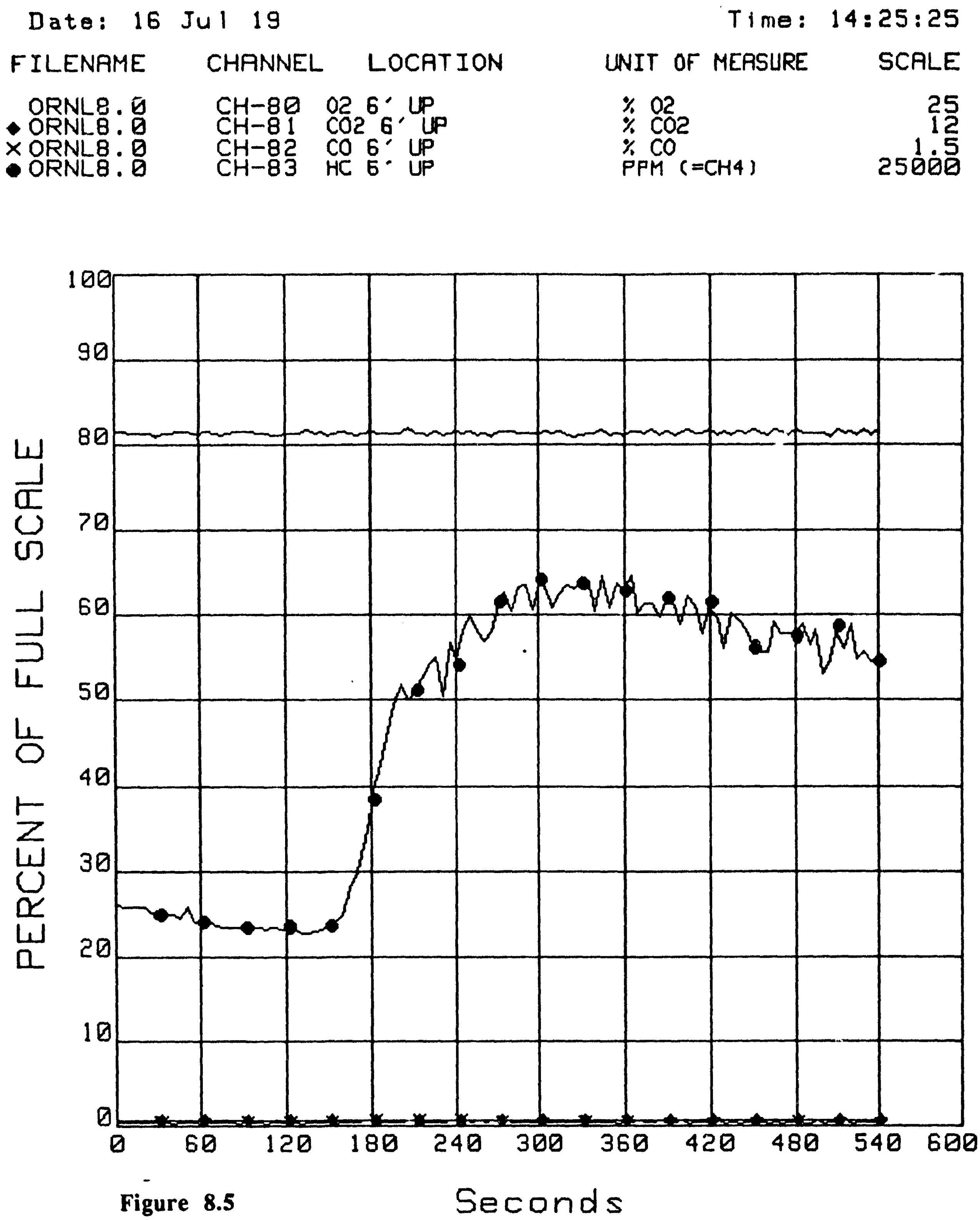
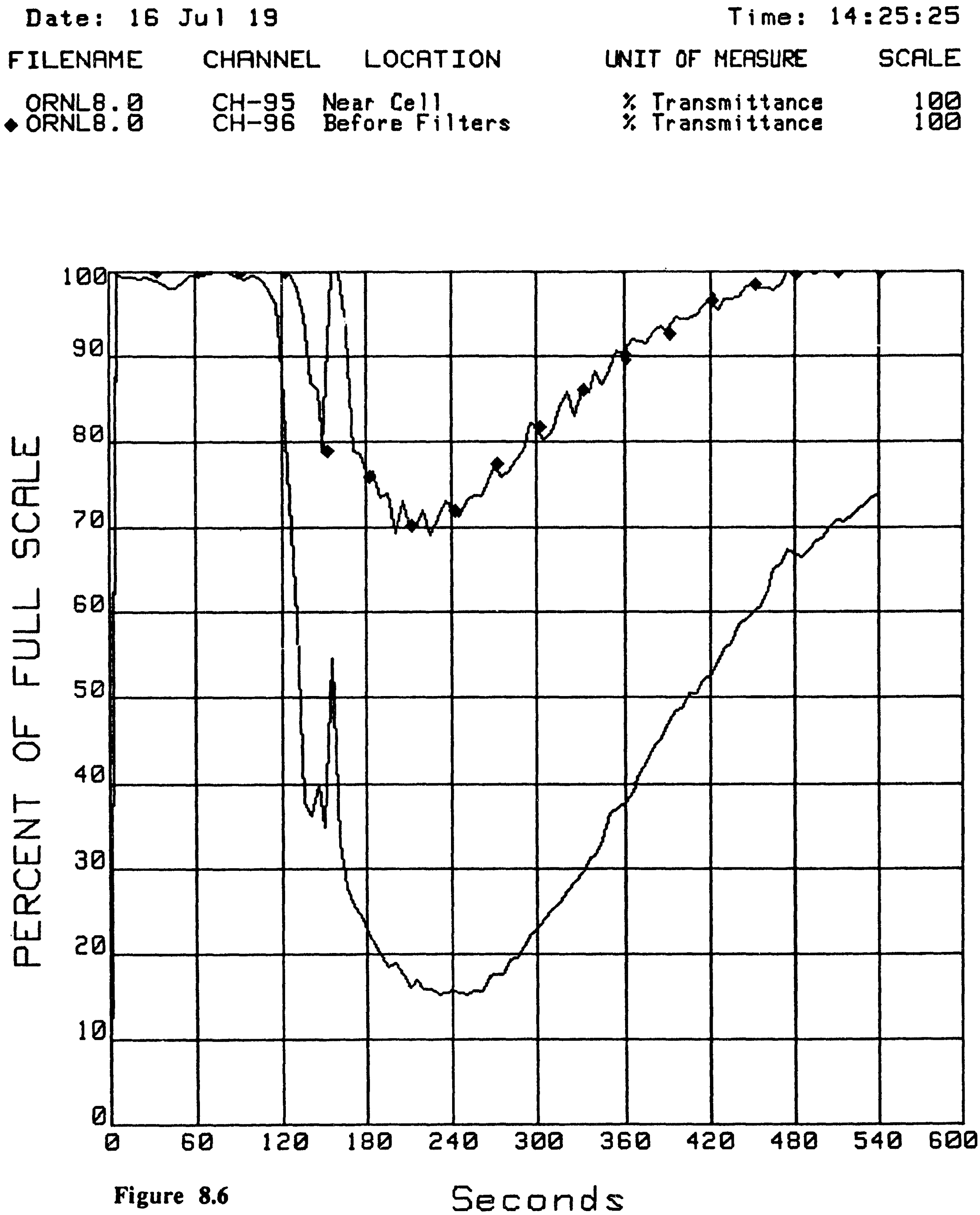

Date: 16 Jul 19
Time: 14:25:25
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL8.0 CH-80 O2 6' UP % O2 25
ORNL8.0 CH-81 CO2 6' UP % CO2 12
ORNL8.0 CH-82 CO 6' UP % CO 1.5
ORNL8.0 CH-83 HC 6' UP PPM (=CH4) 25000
PERCENT OF FULL SCALE
0 10 20 30 40 50 60 70 80 90 100
0 60 120 180 240 300 360 420 480 540 600
Seconds

Figure 8.5



Date: 16 Jul 19
Time: 14:25:25
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL8.0 CH-95 Near Cell % Transmittance 100
◆ ORNL8.0 CH-96 Before Filters % Transmittance 100
PERCENT OF FULL SCALE
0 10 20 30 40 50 60 70 80 90 100
0 60 120 180 240 300 360 420 480 540 600
Seconds

Figure 8.6

Date: 16 Jul 19 Time: 14:25:25

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL8.0	CH-102	Inlet A/F (TFM)	CFM	5000
◆ ORNL8.0	CH-104	Exit A/F (Pitot)	CFM	5000
× ORNL8.0	CH-105	Exit A/F (TFM)	CFM	5000

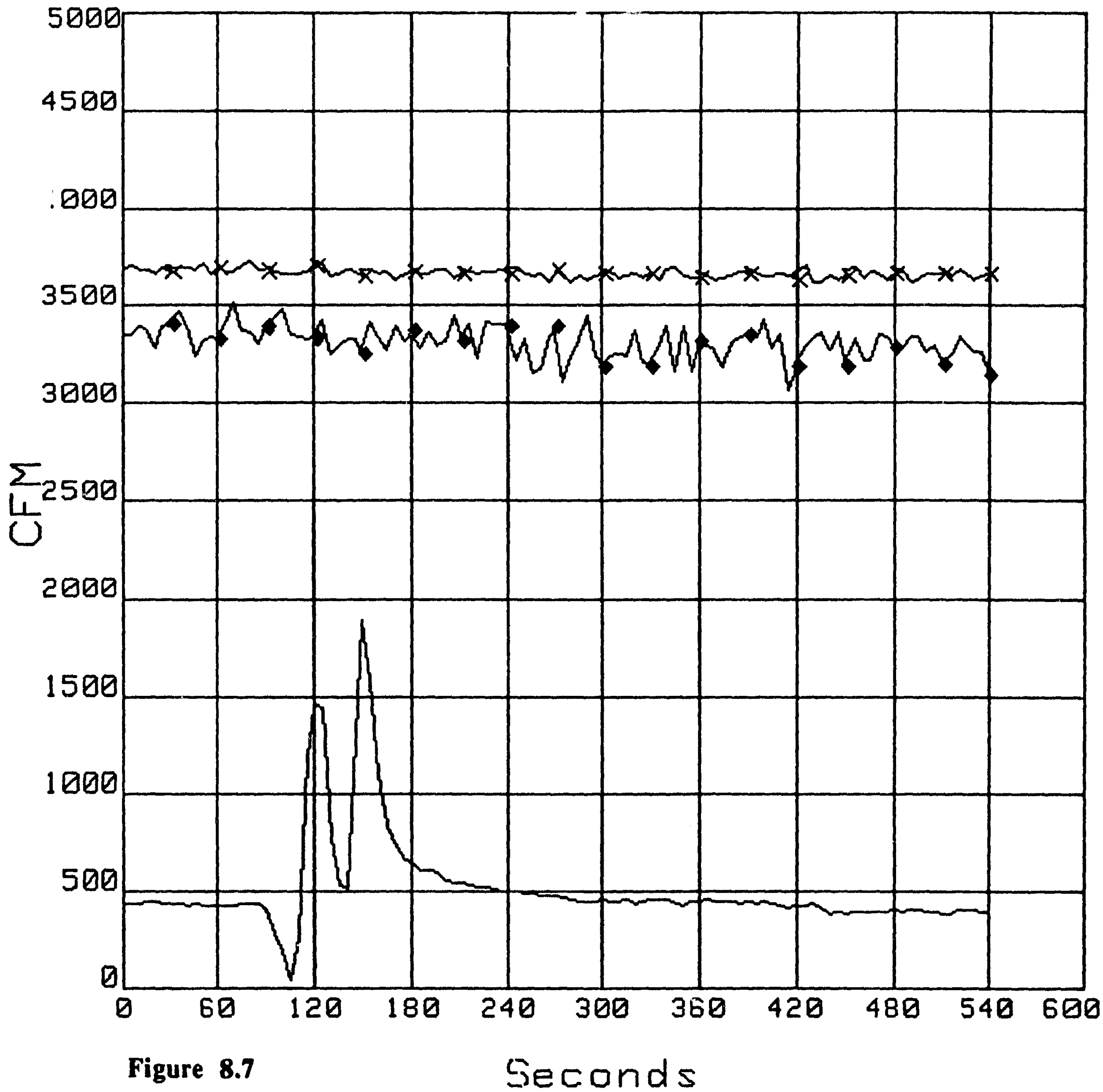


Figure 8.7

Date: 16 Jul 19 Time: 14:25:25

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL8.0	CH-109	Delta P HEPA	INCHES H20	5
◆ ORNL8.0	CH-110	Delta P PreFilter	INCHES H20	5

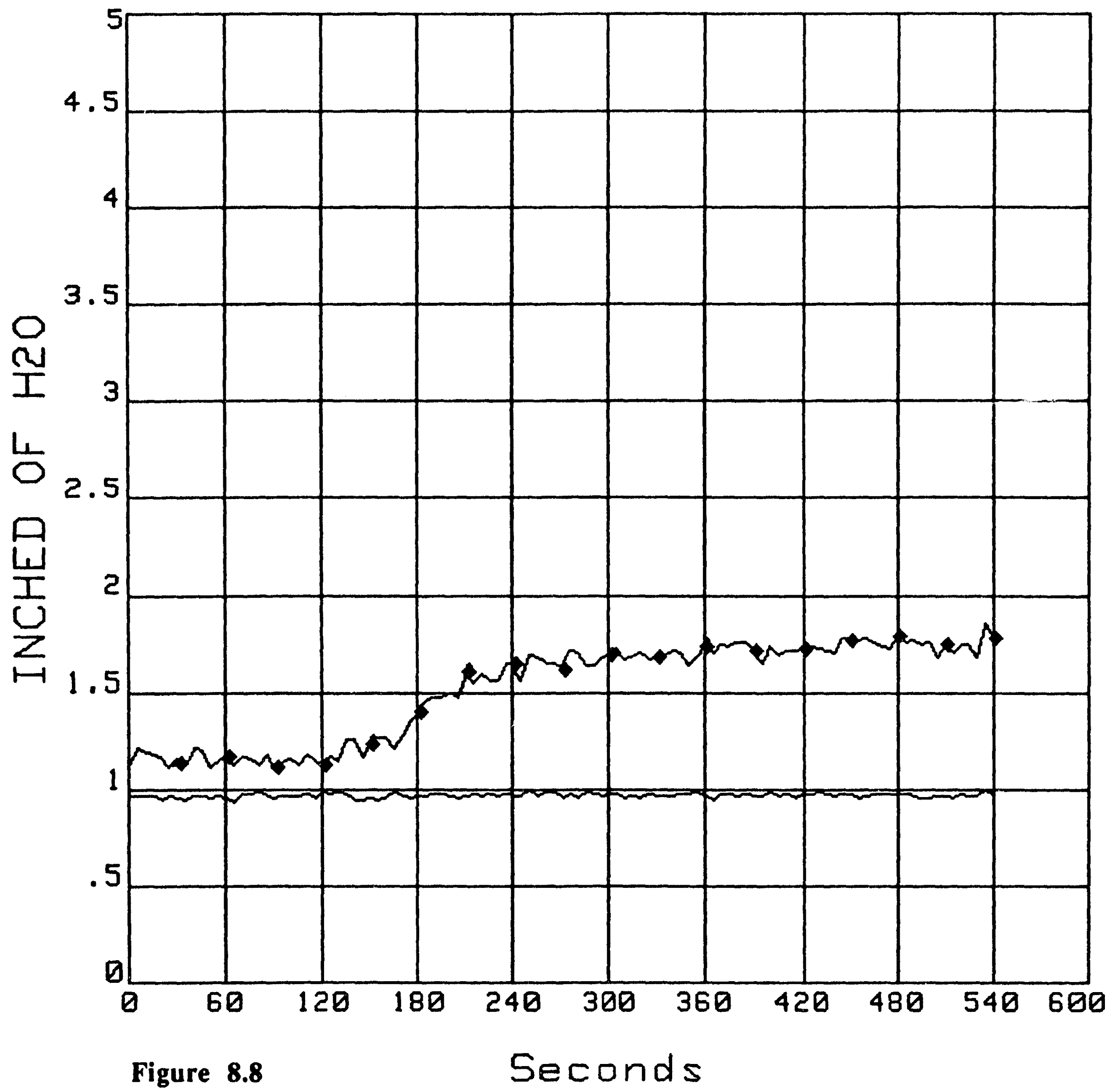


Figure 8.8

Date: 16 Jul 19 Time: 14:25:25

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL8.0	CH-112	Heat Sensor 22'side	INCHES H2O	100
◆ ORNL8.0	CH-113	Heat Sensor 13' side	Inches H2O	100

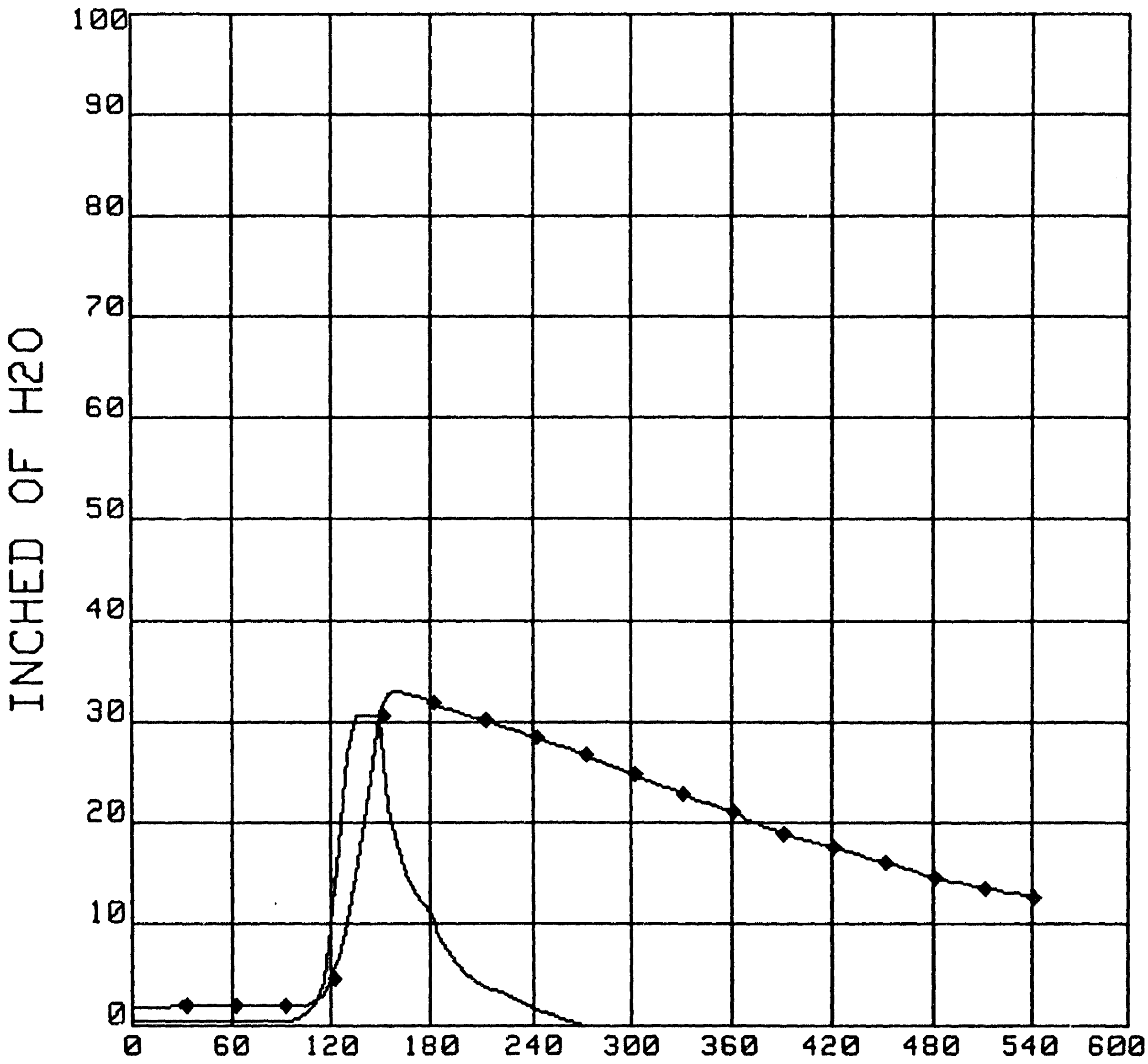


Figure 8.9

Date: 16 Jul 19 Time: 14:25:25

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL8.0	CH-32	CELL MANIFOLD TC	Degrees Celsius	300
◆ ORNL8.0	CH-34	CEL EXH DUCT TC	Degrees Celsius	300
× ORNL8.0	CH-35	EXH/MAKEUP NODE TC	Degrees Celsius	300
● ORNL8.0	CH-36	TC BEFORE PREFILTER	Degrees Celsius	300
■ ORNL8.0	CH-37	TC BEFORE HEPA	Degrees Celsius	300

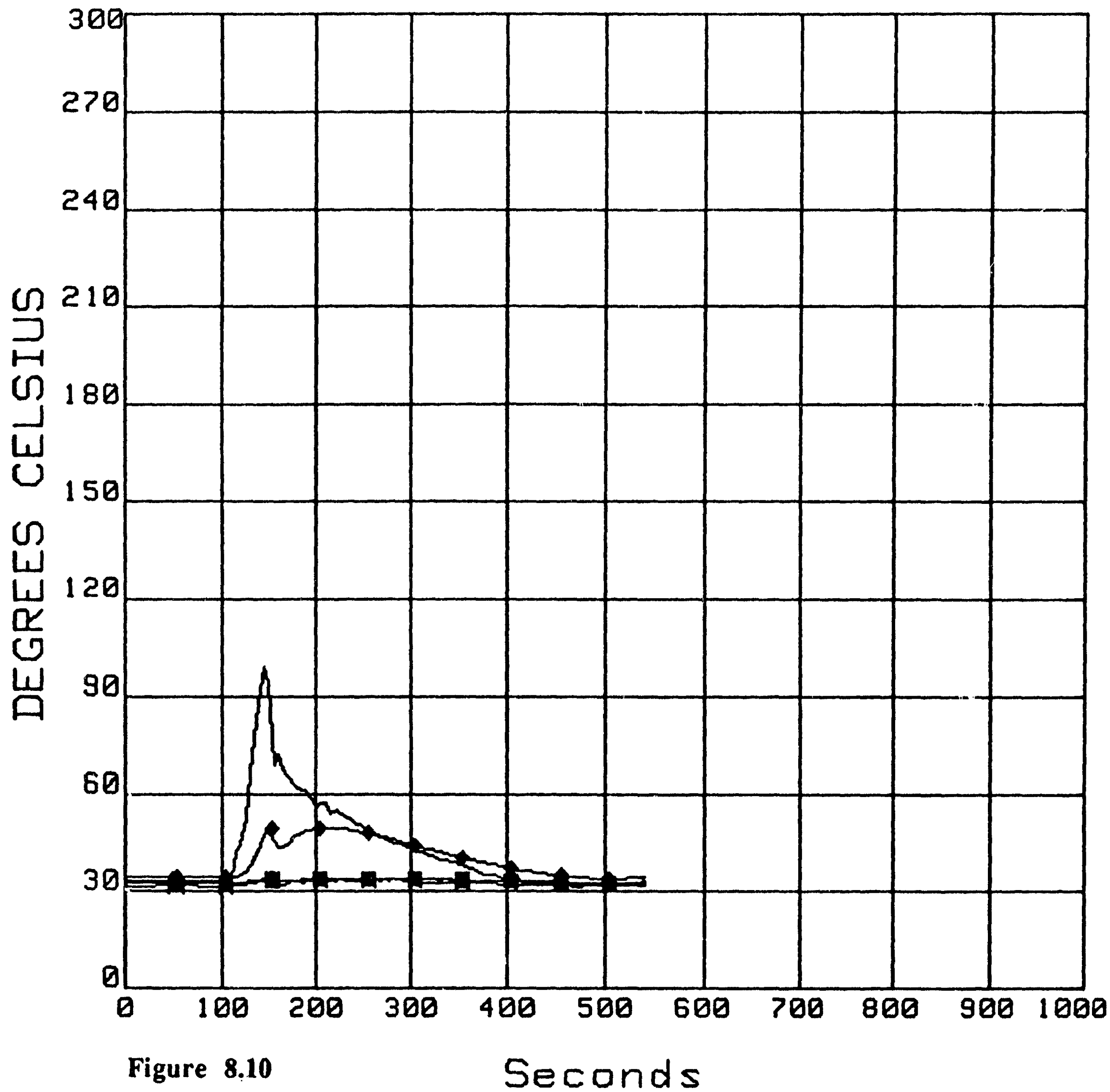


Figure 8.10

Time: 14:25:25

Date: 16 Jul 19

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL8.0	CH-84	O2 12' UP	% O2	25
◆ ORNL8.0	CH-85	CO2 12' UP	% CO2	12
× ORNL8.0	CH-86	CO 12' UP	% CO	1.5
● ORNL8.0	CH-87	HC 12' UP	PPM (=CH4)	25000

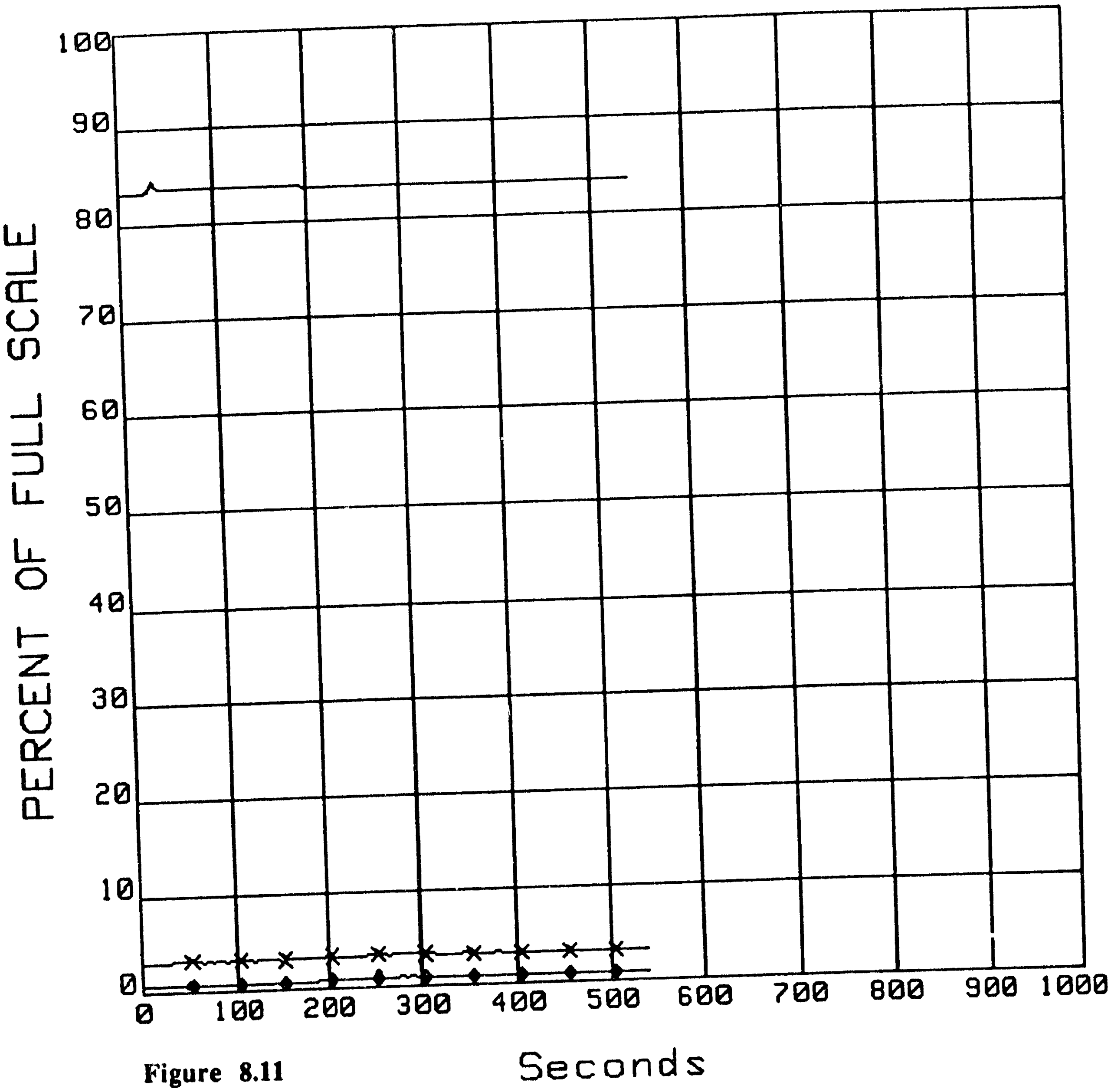


Figure 8.11

Date: 16 Jul 19 Time: 14:25:25

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL8.0	CH-88	O2 Duct Node	% O2	25
◆ ORNL8.0	CH-89	CO2 Duct Node	% CO2	12
× ORNL8.0	CH-90	CO Duct Node	% CO	1.5
● ORNL8.0	CH-91	HC Duct Node	PPM (=CH4)	25000

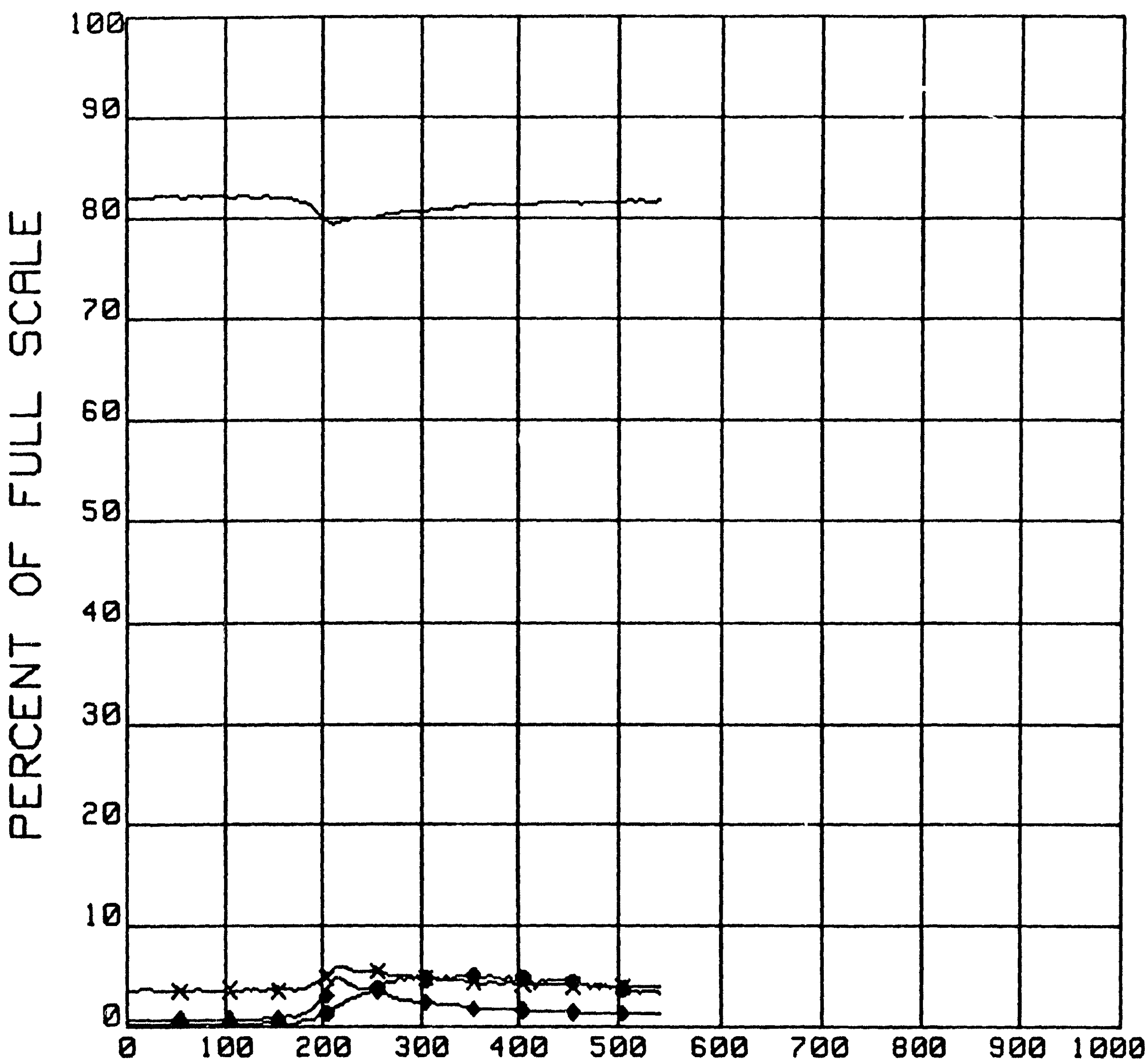


Figure 8.12

Date: 16 Jul 19 Time: 15:26:54

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL8.1	CH-102	Inlet A/F (TFM)	CFM	5000
◆ ORNL8.1	CH-104	Exit A/F (Pitot)	CFM	5000
× ORNL8.1	CH-105	Exit A/F (TFM)	CFM	5000

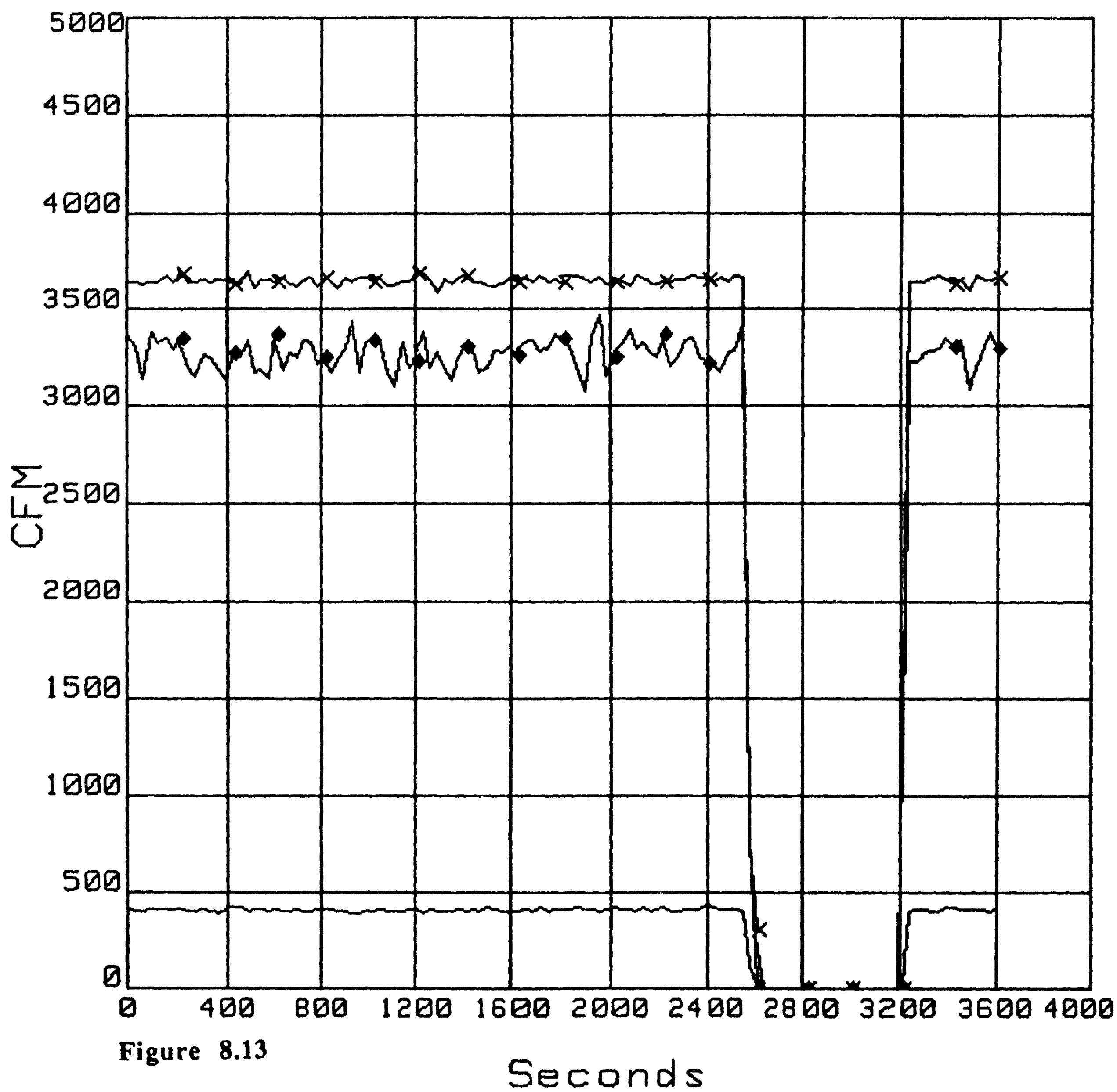


Figure 8.13

Date: 16 Jul 19 Time: 15:26:54

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL8.1	CH-109	Delta P HEPA	INCHES H20	5
◆ ORNL8.1	CH-110	Delta P PreFilter	INCHES H20	5

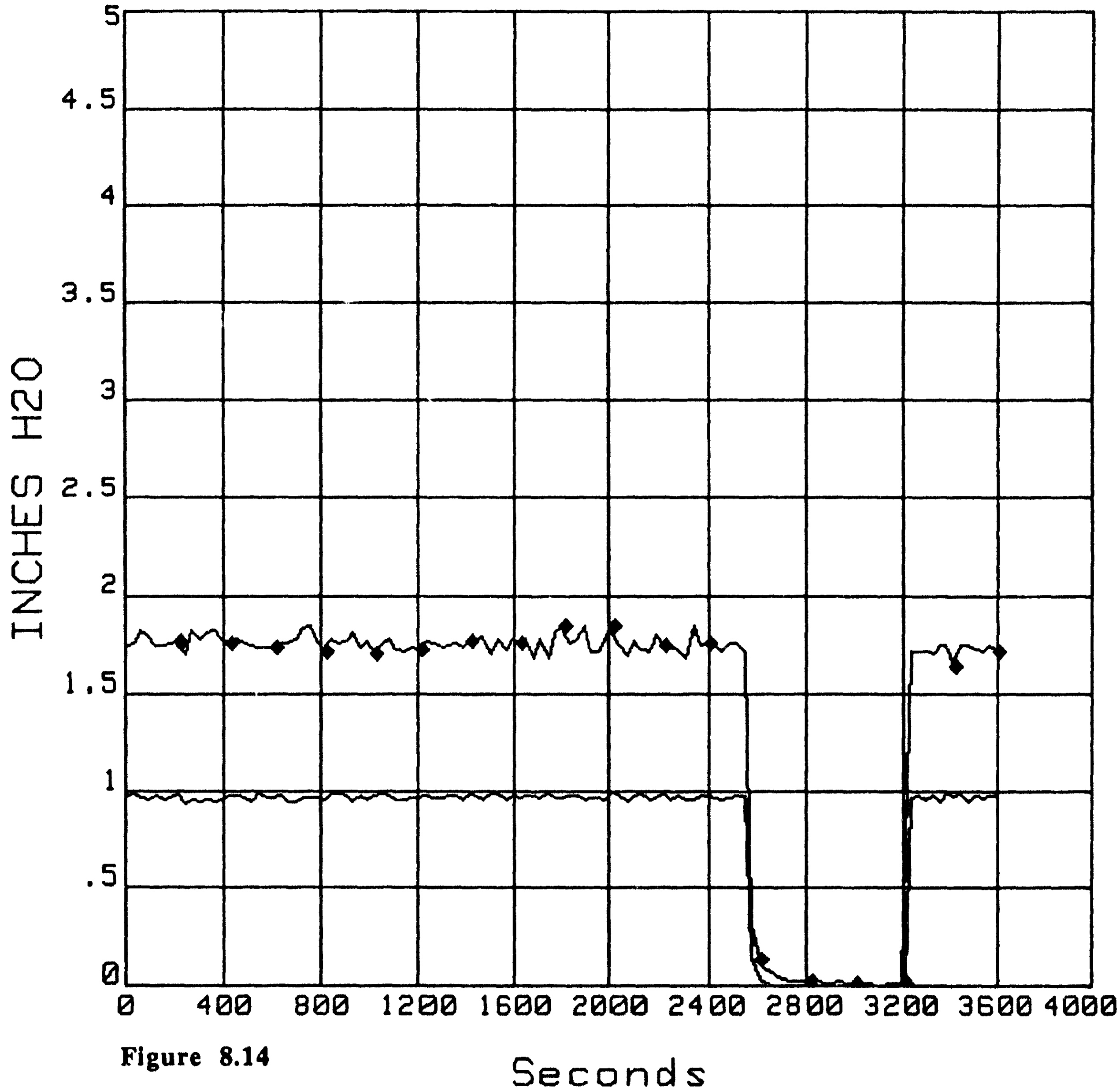


Figure 8.14

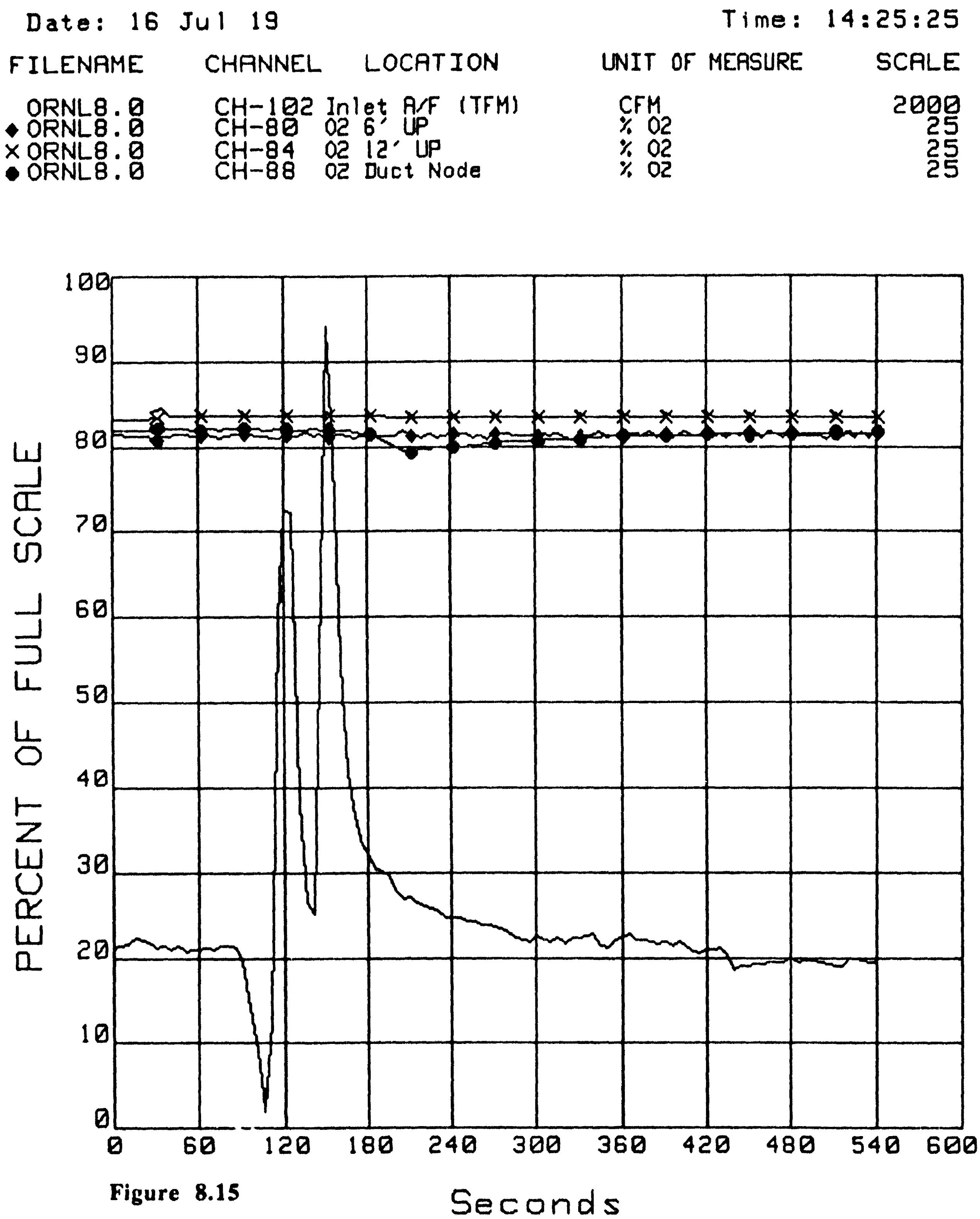

Date: 16 Jul 19
Time: 14:25:25
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL8.0 CH-102 Inlet A/F (TFM) CFM 2000
ORNL8.0 CH-80 02 6' UP % 02 25
ORNL8.0 CH-84 02 12' UP % 02 25
ORNL8.0 CH-88 02 Duct Node % 02 25
PERCENT OF FULL SCALE
Seconds
0 10 20 30 40 50 60 70 80 90 100
0 60 120 180 240 300 360 420 480 540 600

Figure 8.15

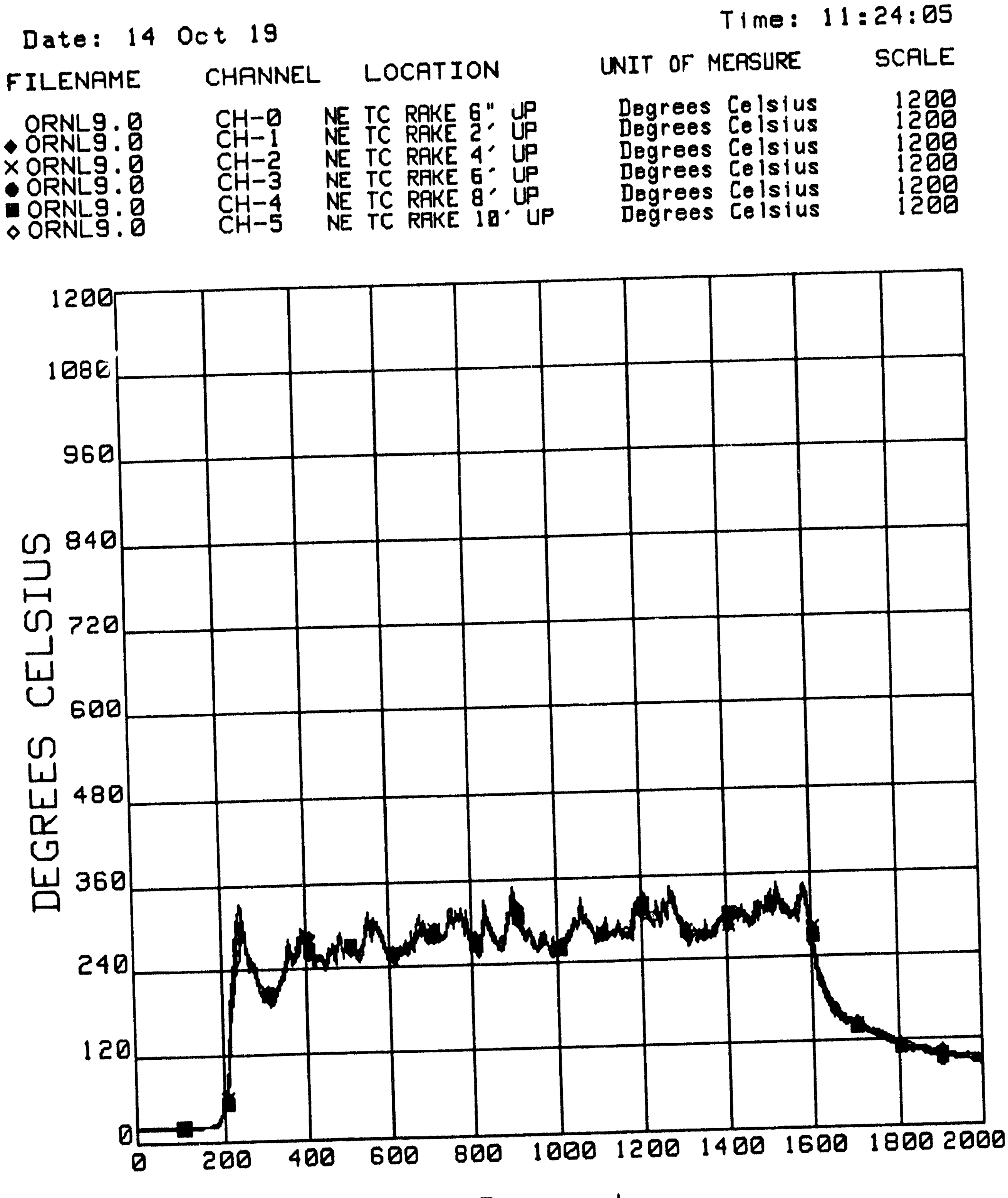

Date: 14 Oct 19
Time: 11:24:05
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL9.0 CH-0 NE TC RAKE 6" UP Degrees Celsius 1200
ORNL9.0 CH-1 NE TC RAKE 2' UP Degrees Celsius 1200
ORNL9.0 CH-2 NE TC RAKE 4' UP Degrees Celsius 1200
ORNL9.0 CH-3 NE TC RAKE 6' UP Degrees Celsius 1200
ORNL9.0 CH-4 NE TC RAKE 8' UP Degrees Celsius 1200
ORNL9.0 CH-5 NE TC RAKE 10' UP Degrees Celsius 1200
DEGREES CELSIUS
1200
1080
960
840
720
600
480
360
240
120
0
0 200 400 600 800 1000 1200 1400 1600 1800 2000
Seconds

Figure 9.1

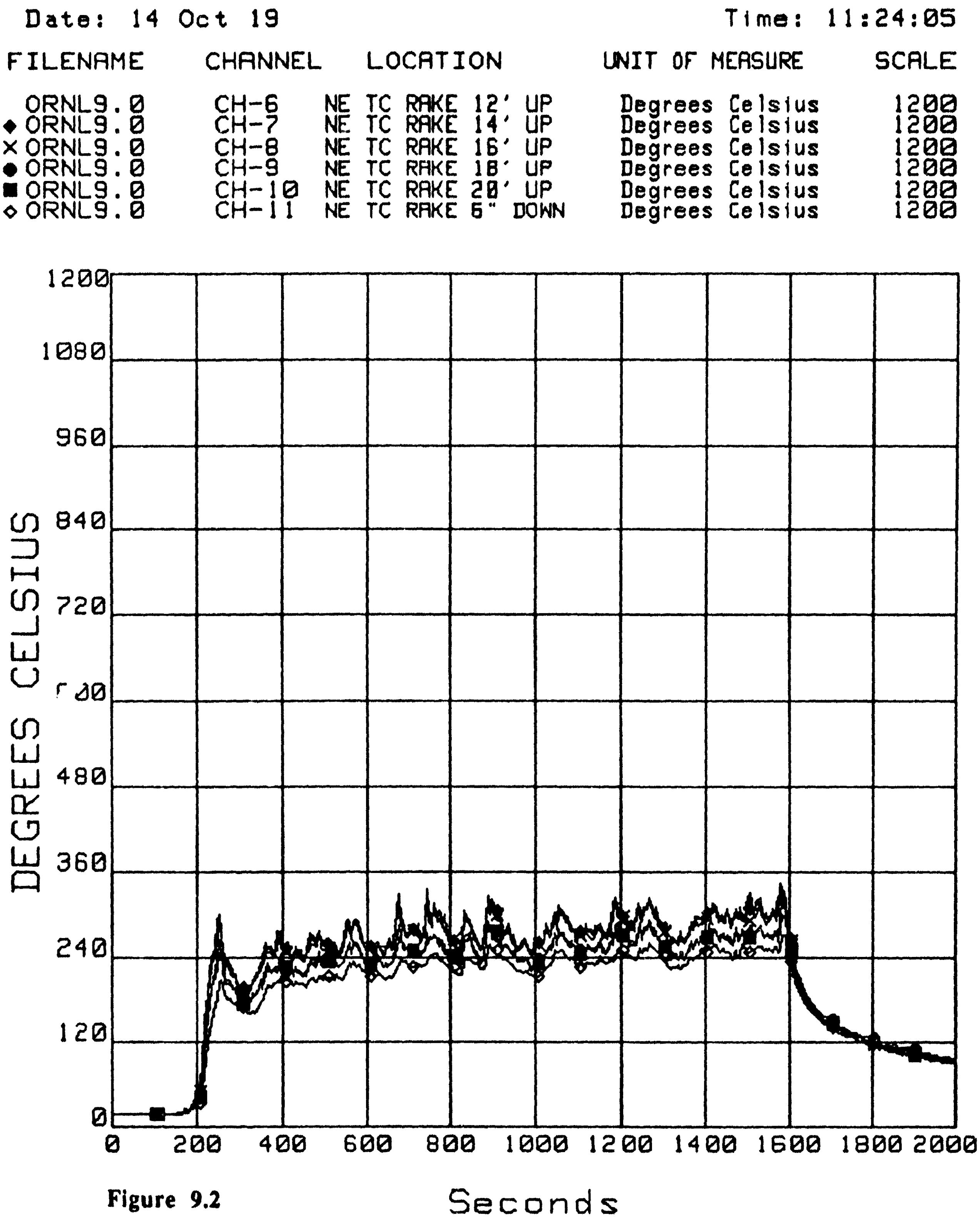

Date: 14 Oct 19
Time: 11:24:05
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL9.0 CH-6 NE TC RAKE 12' UP Degrees Celsius 1200
◆ ORNL9.0 CH-7 NE TC RAKE 14' UP Degrees Celsius 1200
× ORNL9.0 CH-8 NE TC RAKE 16' UP Degrees Celsius 1200
● ORNL9.0 CH-9 NE TC RAKE 18' UP Degrees Celsius 1200
■ ORNL9.0 CH-10 NE TC RAKE 20' UP Degrees Celsius 1200
◇ ORNL9.0 CH-11 NE TC RAKE 6" DOWN Degrees Celsius 1200
DEGREES CELSIUS
1200
1080
960
840
720
480
360
240
120
0
0 200 400 600 800 1000 1200 1400 1600 1800 2000
Seconds

Figure 9.2

Date: 14 Oct 19

Time: 11:24:05

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL9.0	CH-20	So TC RAKE 6" UP	Degrees Celsius	1200
◆ ORNL9.0	CH-21	So TC RAKE 2' UP	Degrees Celsius	1200
× ORNL9.0	CH-22	So TC RAKE 4' UP	Degrees Celsius	1200
● ORNL9.0	CH-23	So TC RAKE 6' UP	Degrees Celsius	1200

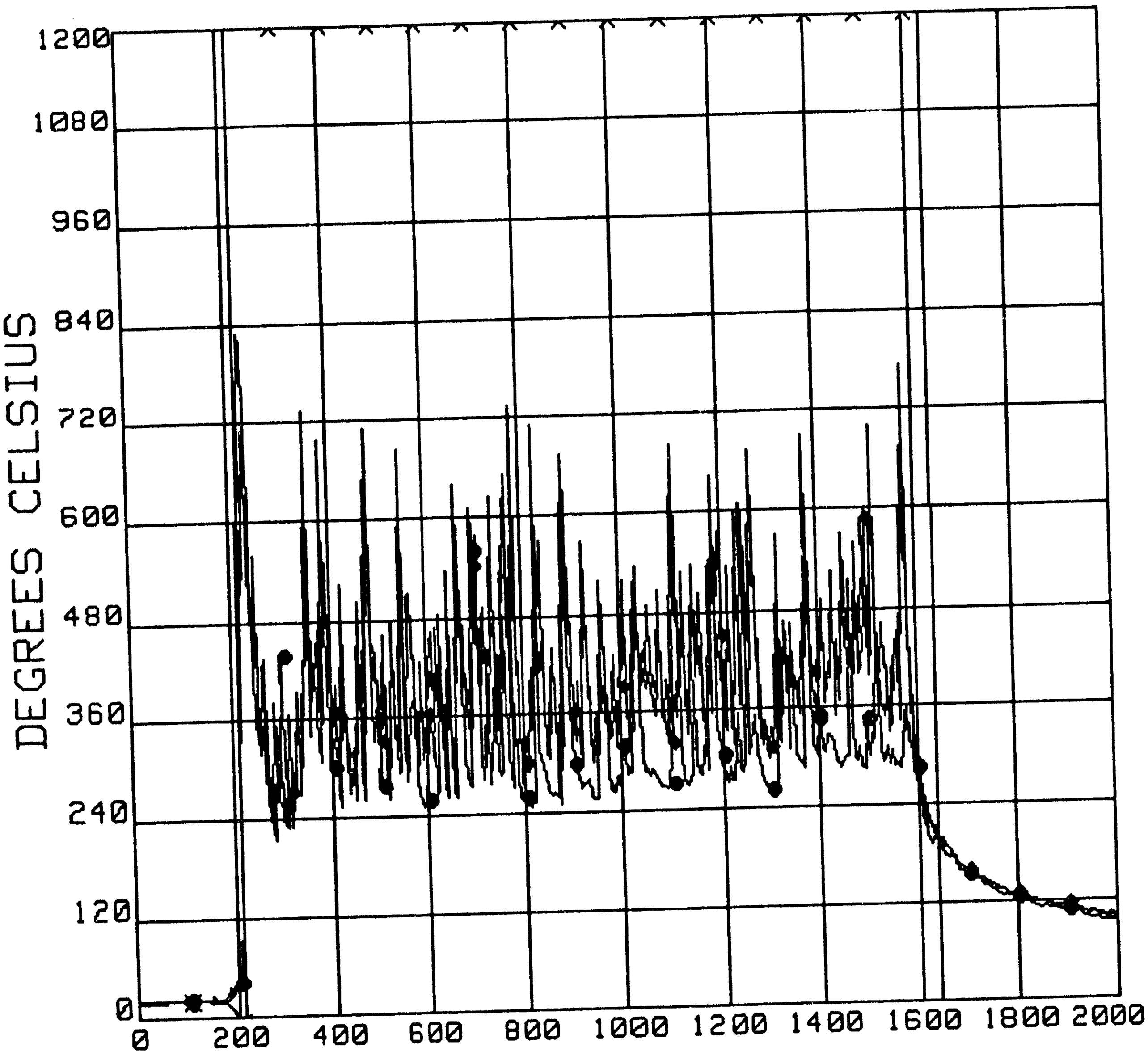


Figure 9.3

Date: 14 Oct 19 Time: 11:24:05

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL9.0	CH-27	TOP So WINDOW TC	Degrees Celsius	1200
◆ ORNL9.0	CH-28	TOP No WINDOW TC	Degrees Celsius	1200
× ORNL9.0	CH-29	BOTTOM So WINDOW TC	Degrees Celsius	1200
● ORNL9.0	CH-30	BOTTOM No WINDOW TC	Degrees Celsius	1200

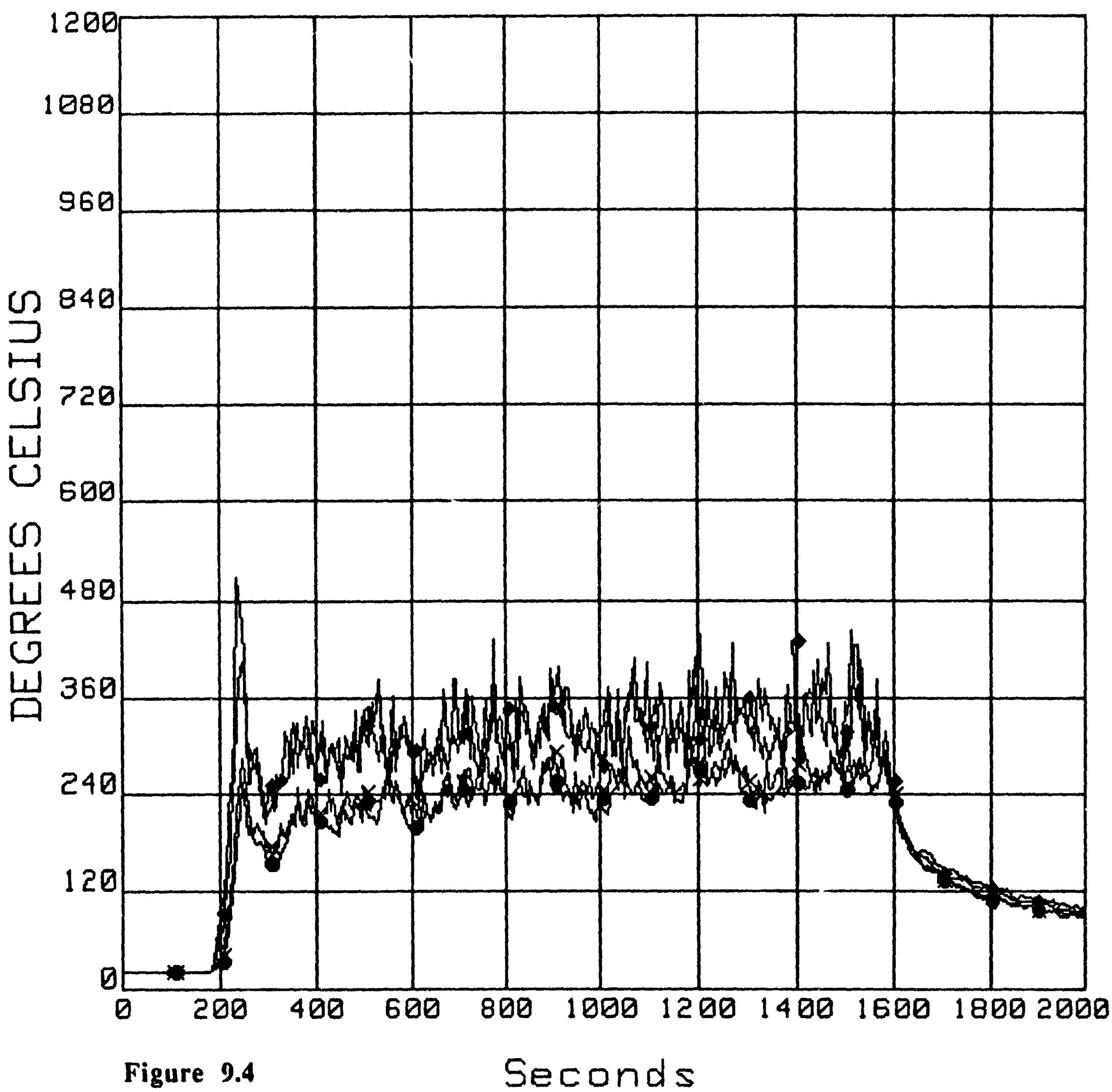


Figure 9.4

Date: 14 Oct 19 Time: 11:24:05

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL9.0	CH-80	O2 6´ UP	% O2	25
◆ ORNL9.0	CH-81	CO2 6´ UP	% CO2	12
× ORNL9.0	CH-82	CO 6´ UP	% CO	1.5
● ORNL9.0	CH-83	HC 6´ UP	PPM (=CH4)	25000

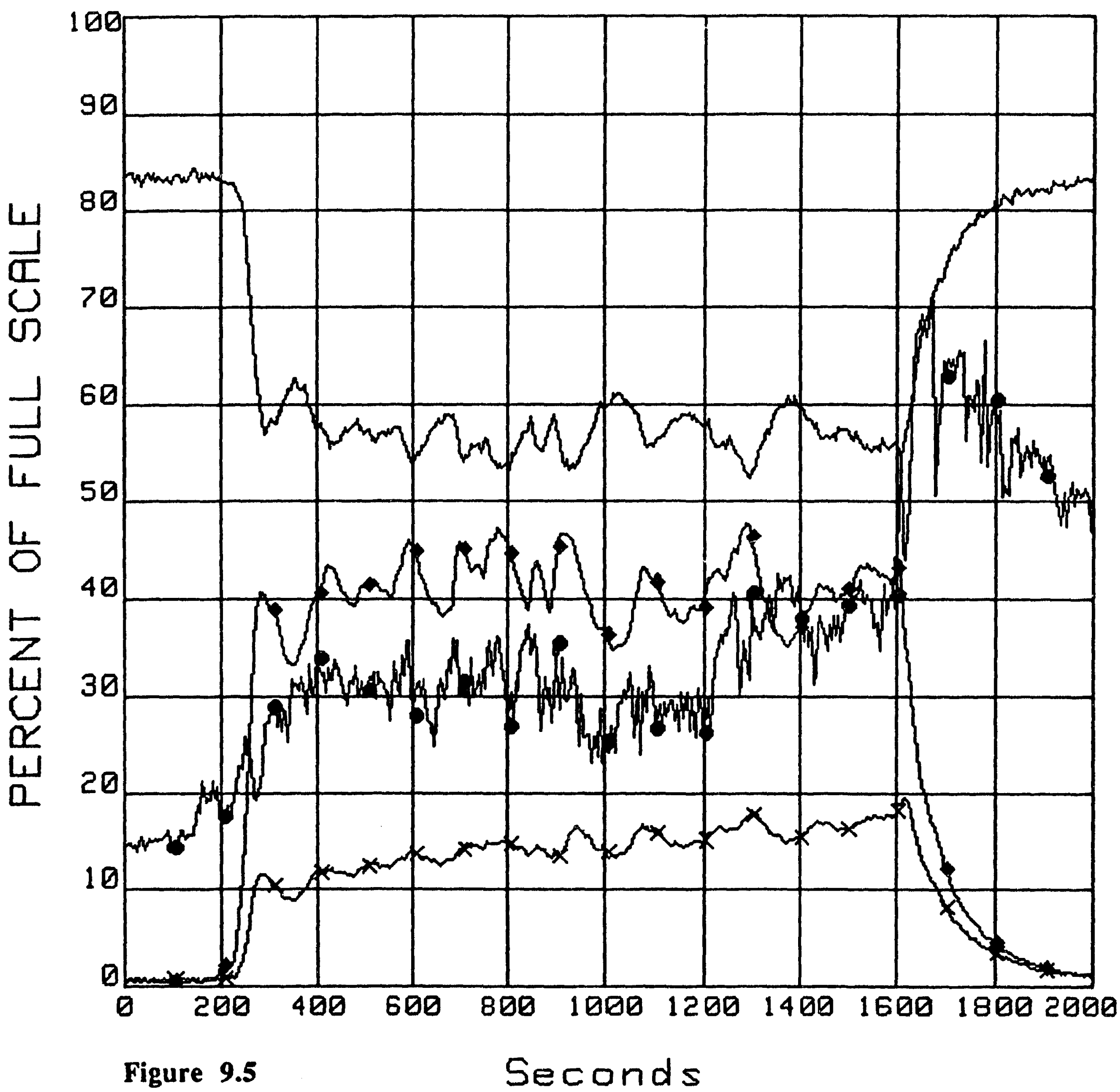


Figure 9.5

Date: 14 Oct 19 Time: 11:24:05

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL9.0	CH-95	Near Cell	% Transmittance	100
◆ ORNL9.0	CH-96	Before Filters	% Transmittance	100

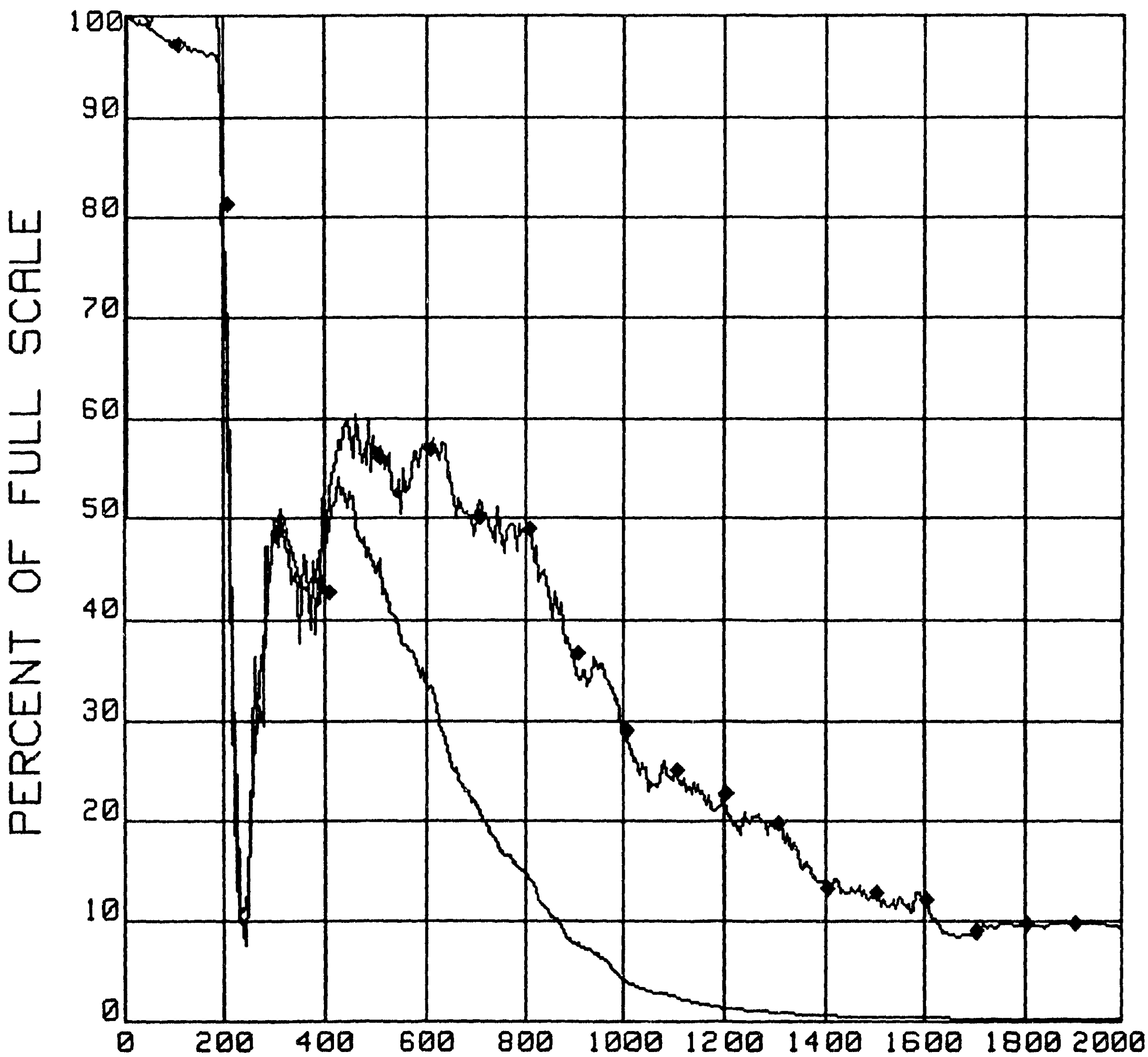


Figure 9.6

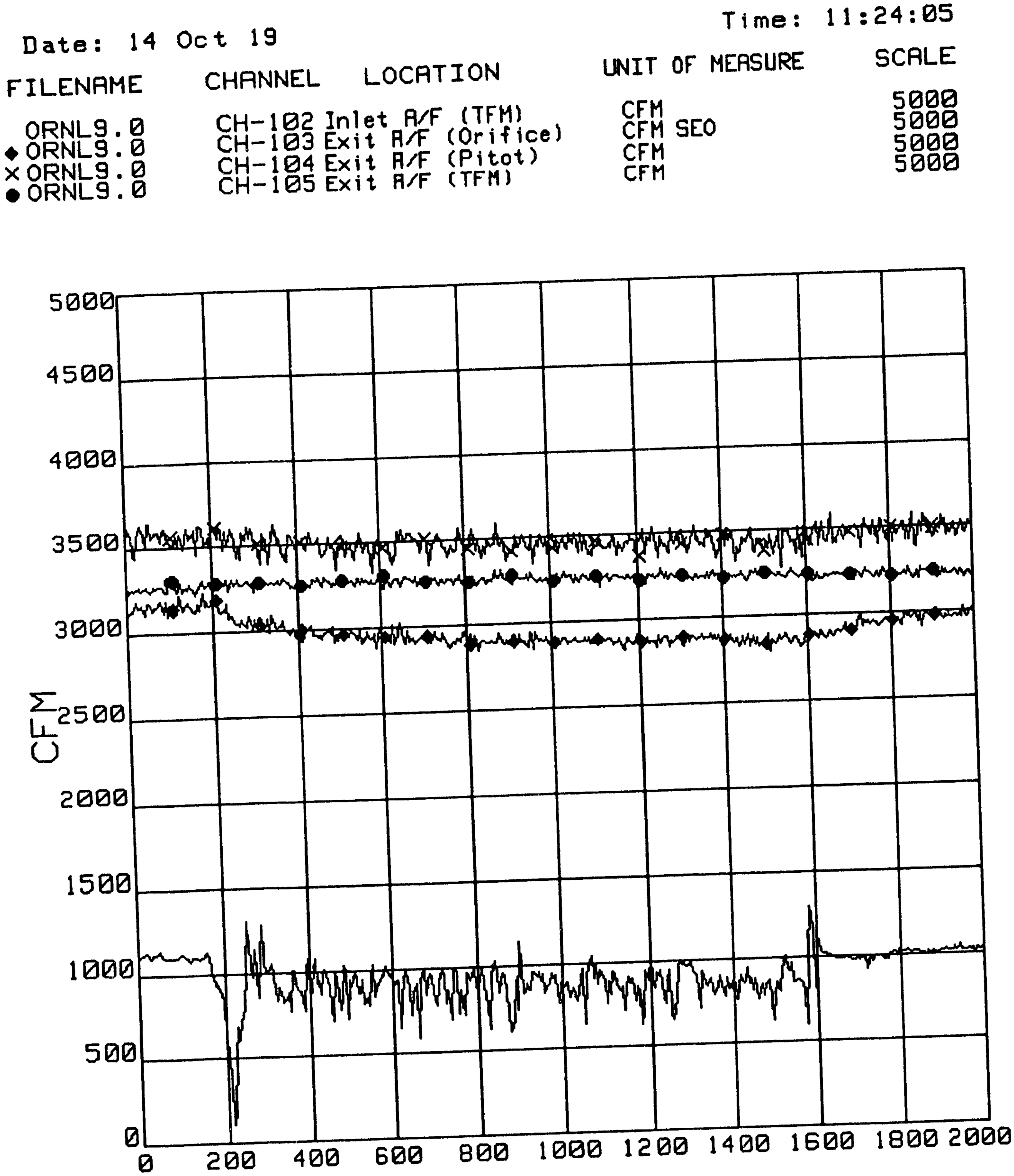

Time: 11:24:05
Date: 14 Oct 19
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL9.0 CH-102 Inlet A/F (TFM) CFM 5000
◆ ORNL9.0 CH-103 Exit A/F (Orifice) CFM SEO 5000
× ORNL9.0 CH-104 Exit A/F (Pitot) CFM 5000
● ORNL9.0 CH-105 Exit A/F (TFM) CFM 5000
CFM
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Seconds

Figure 9.7

Date: 14 Oct 19 Time: 11:24:05

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL9.0	CH-109	Delta P HEPA	INCHES H20	5
◆ ORNL9.0	CH-110	Delta P PreFilter	INCHES H20	5

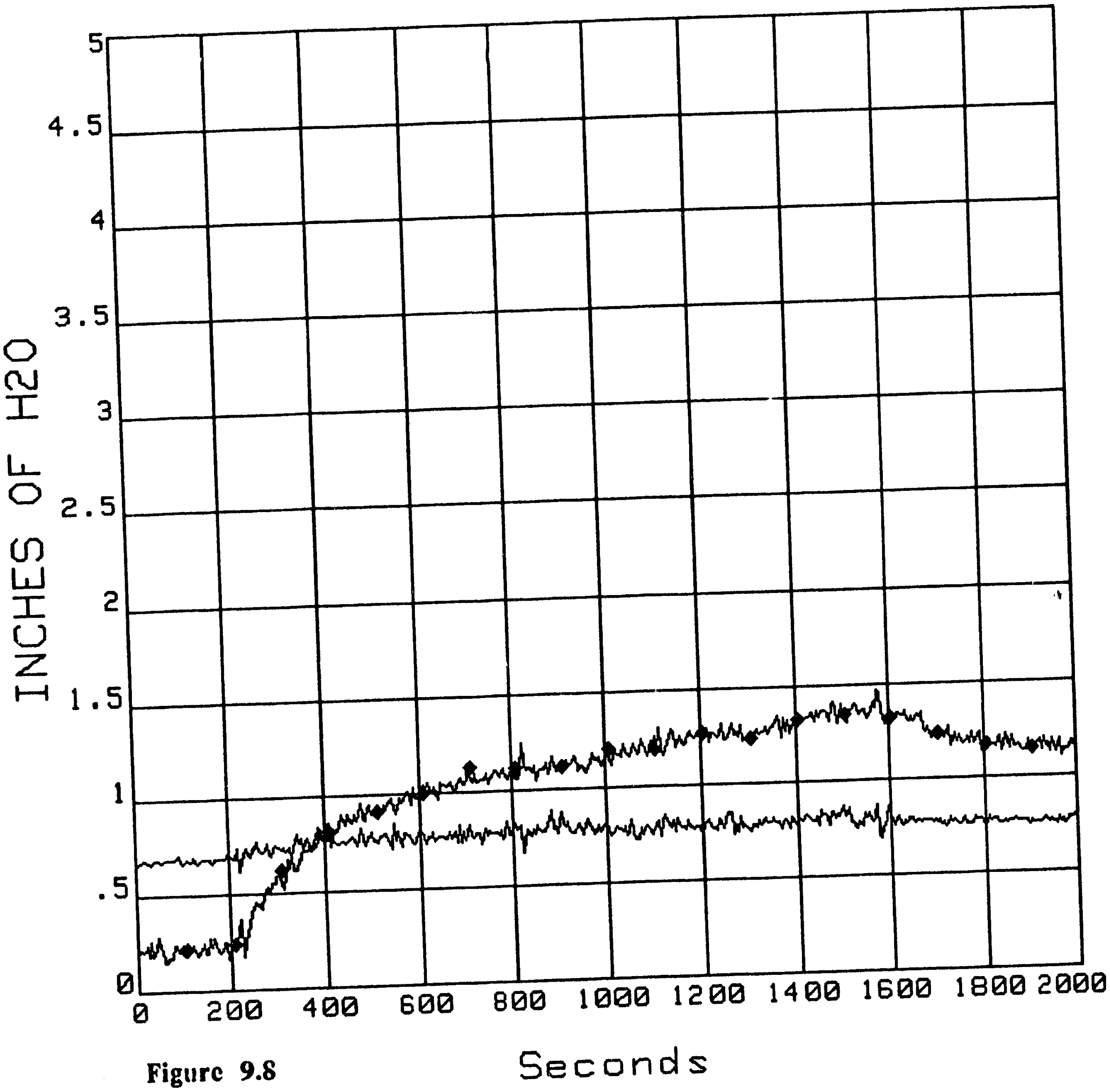


Figure 9.8

Date: 14 Oct 19 Time: 11:24:05

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL9.0	CH-112	Heat Sensor 22'side	INCHES H2O	100
◆ ORNL9.0	CH-113	Heat Sensor 13' side	Inches H2O	100

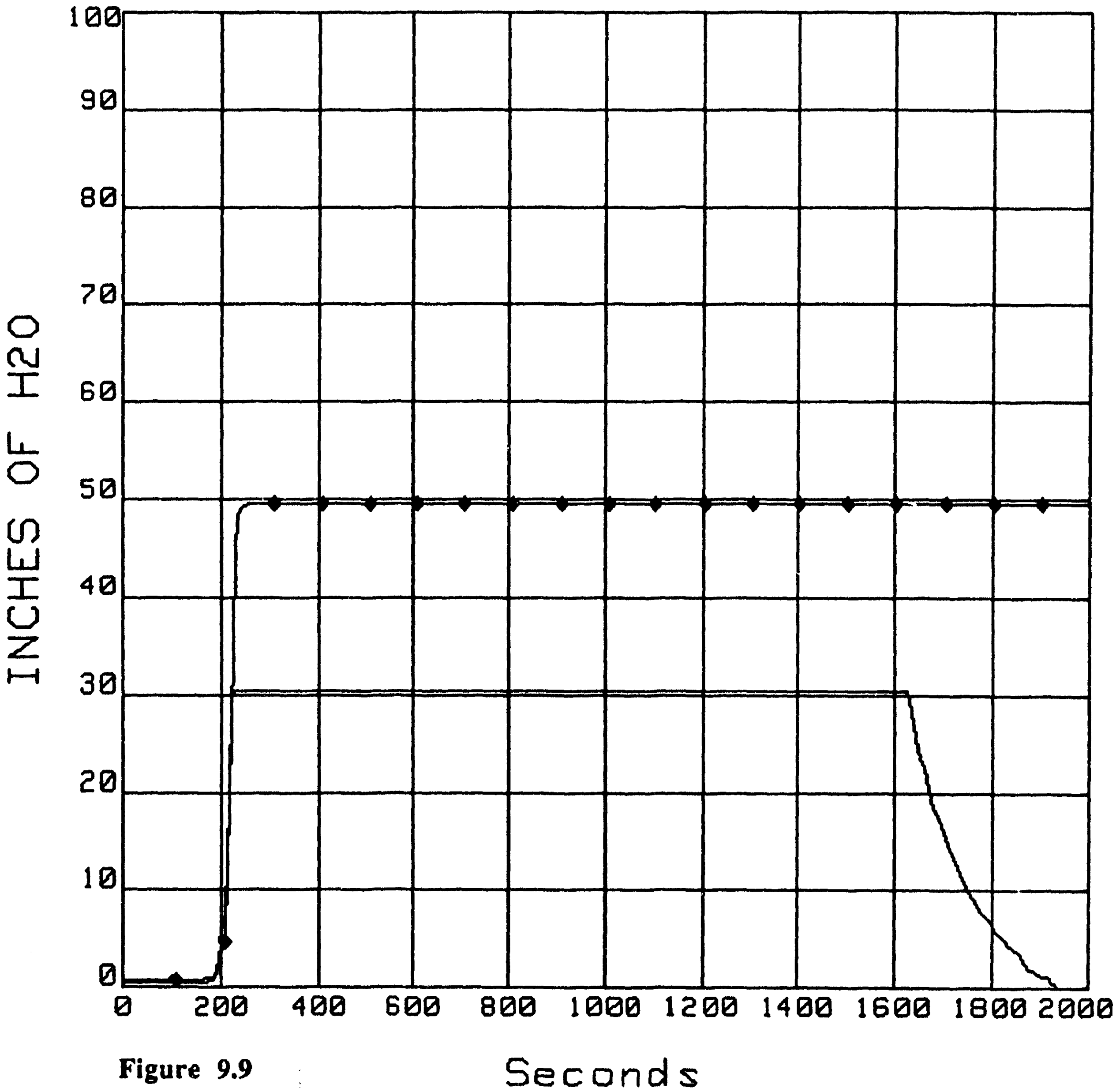


Figure 9.9

Date: 14 Oct 19 Time: 11:24:05

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL9.0	CH-32	CELL MANIFOLD TC	Degrees Celsius	300
◆ ORNL9.0	CH-34	CEL EXH DUCT TC	Degrees Celsius	300
× ORNL9.0	CH-35	EXH/MAKEUP NODE TC	Degrees Celsius	300
● ORNL9.0	CH-36	TC BEFORE PREFILTER	Degrees Celsius	300
■ ORNL9.0	CH-37	TC BEFORE HEPA	Degrees Celsius	300

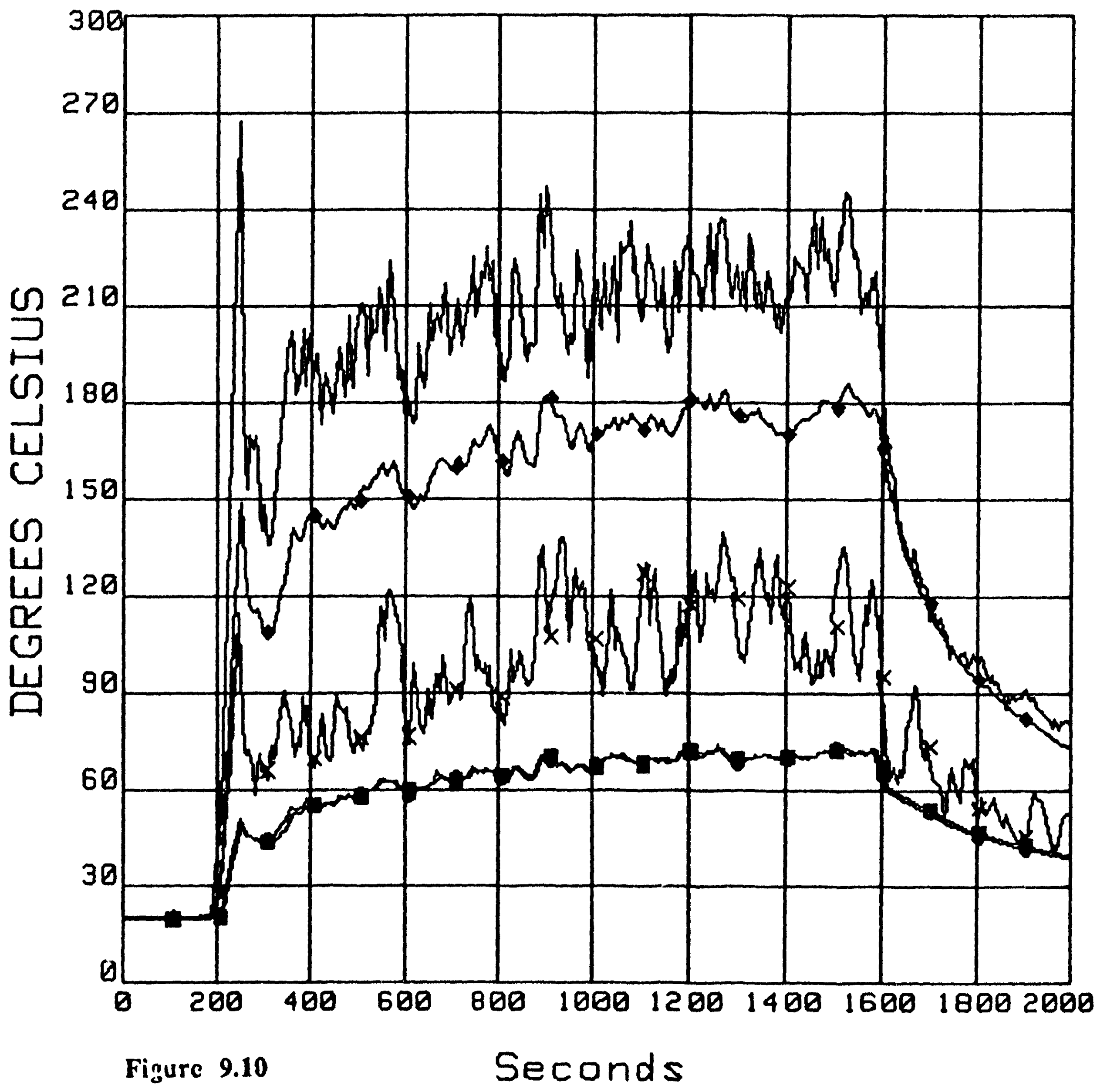


Figure 9.10

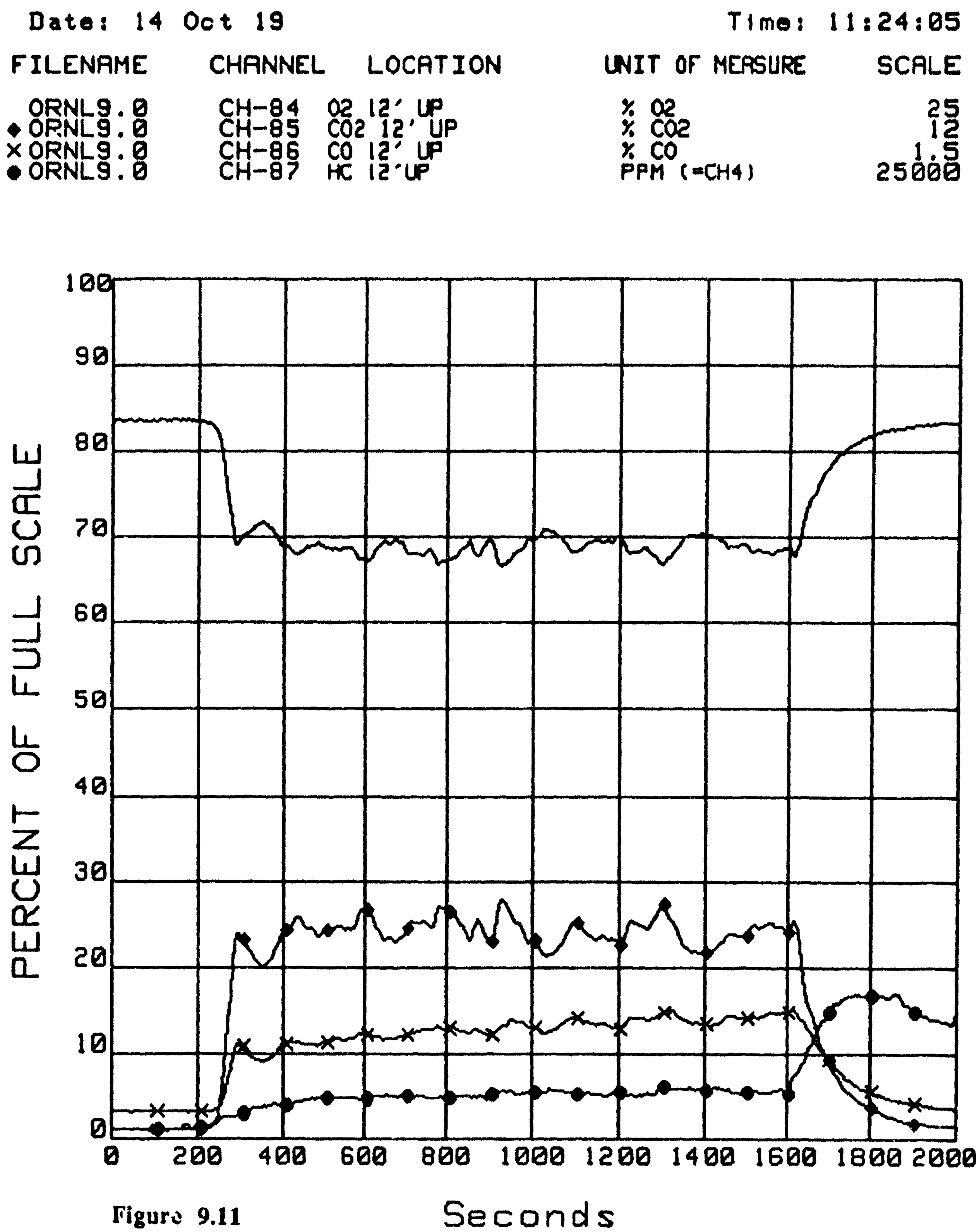

Date: 14 Oct 19
Time: 11:24:05
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL9.0 CH-84 02 12' UP % 02 25
◆ORNL9.0 CH-85 CO2 12' UP % CO2 12
×ORNL9.0 CH-86 CO 12' UP % CO 1.5
●ORNL9.0 CH-87 HC 12'UP PPM (=CH4) 25000
PERCENT OF FULL SCALE
100
90
80
70
60
50
40
30
20
10
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Seconds

Figure 9.11

Date: 14 Oct 19 Time: 11:24:05

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL9.0	CH-88	O2 Duct Node	% O2	25
◆ ORNL9.0	CH-89	CO2 Duct Node	% CO2	12
× ORNL9.0	CH-90	CO Duct Node	% CO	1.5
● ORNL9.0	CH-91	HC Duct Node	PPM (=CH4)	25000

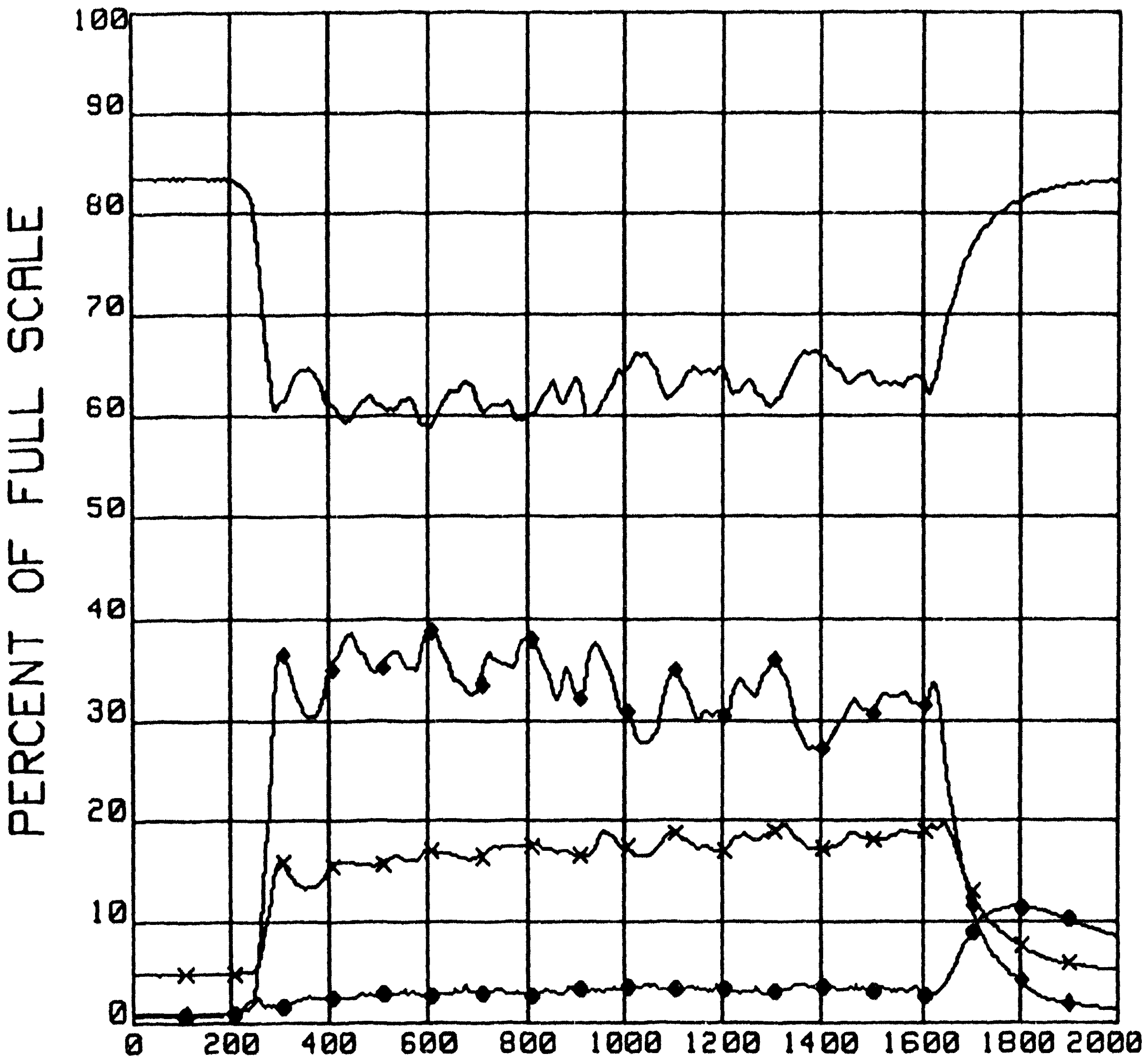


Figure 9.12

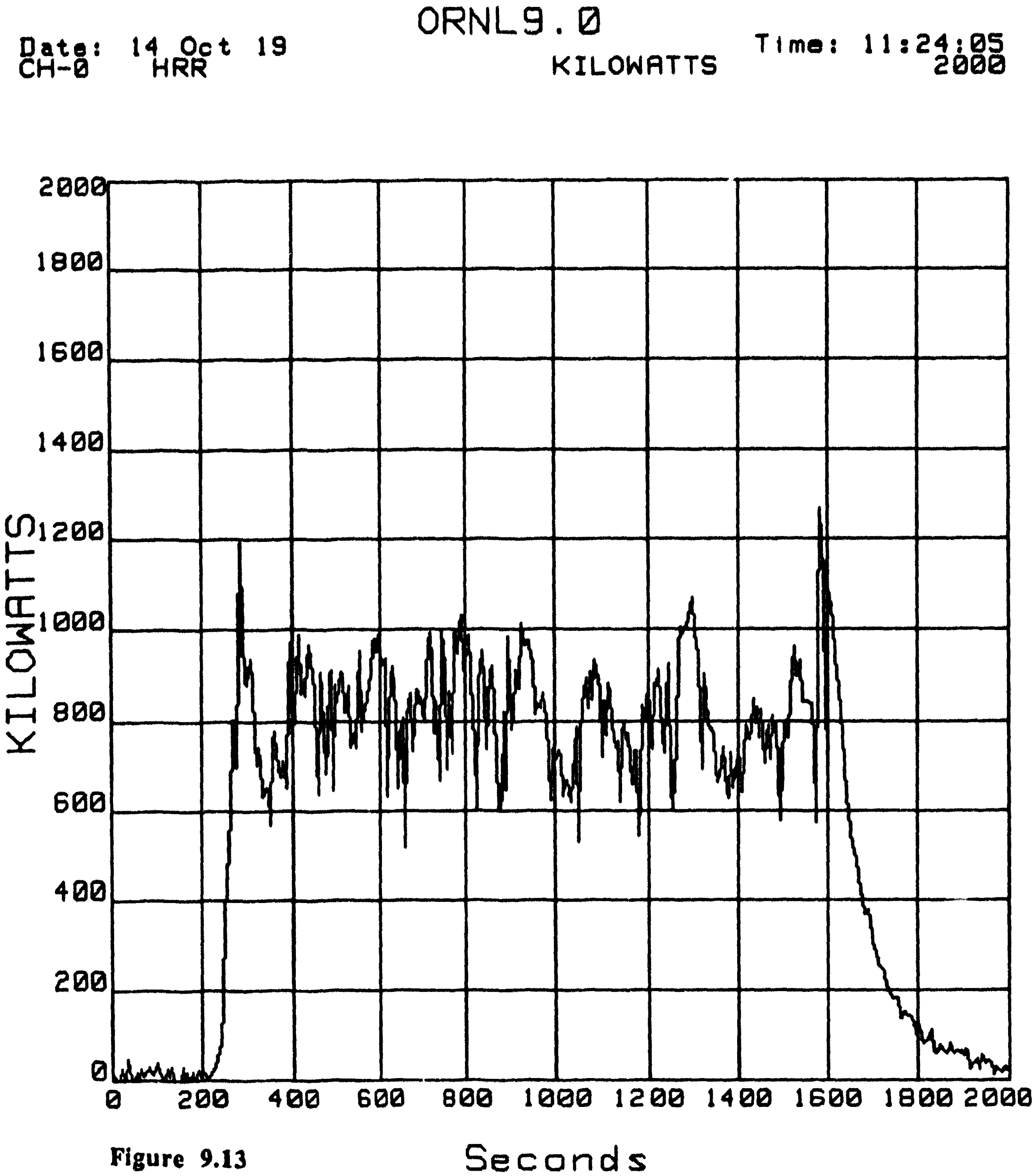


Figure 9.13

No. of channels=73

Date: 14 Oct 19 Time: 11:24:05

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL9.0	CH-102	Inlet A/F (TFM)	CFM	2000
◆ ORNL9.0	CH-80	O2 6' UP	% O2	25
× ORNL9.0	CH-84	O2 12' UP	% O2	25
● ORNL9.0	CH-88	O2 Duct Node	% O2	25

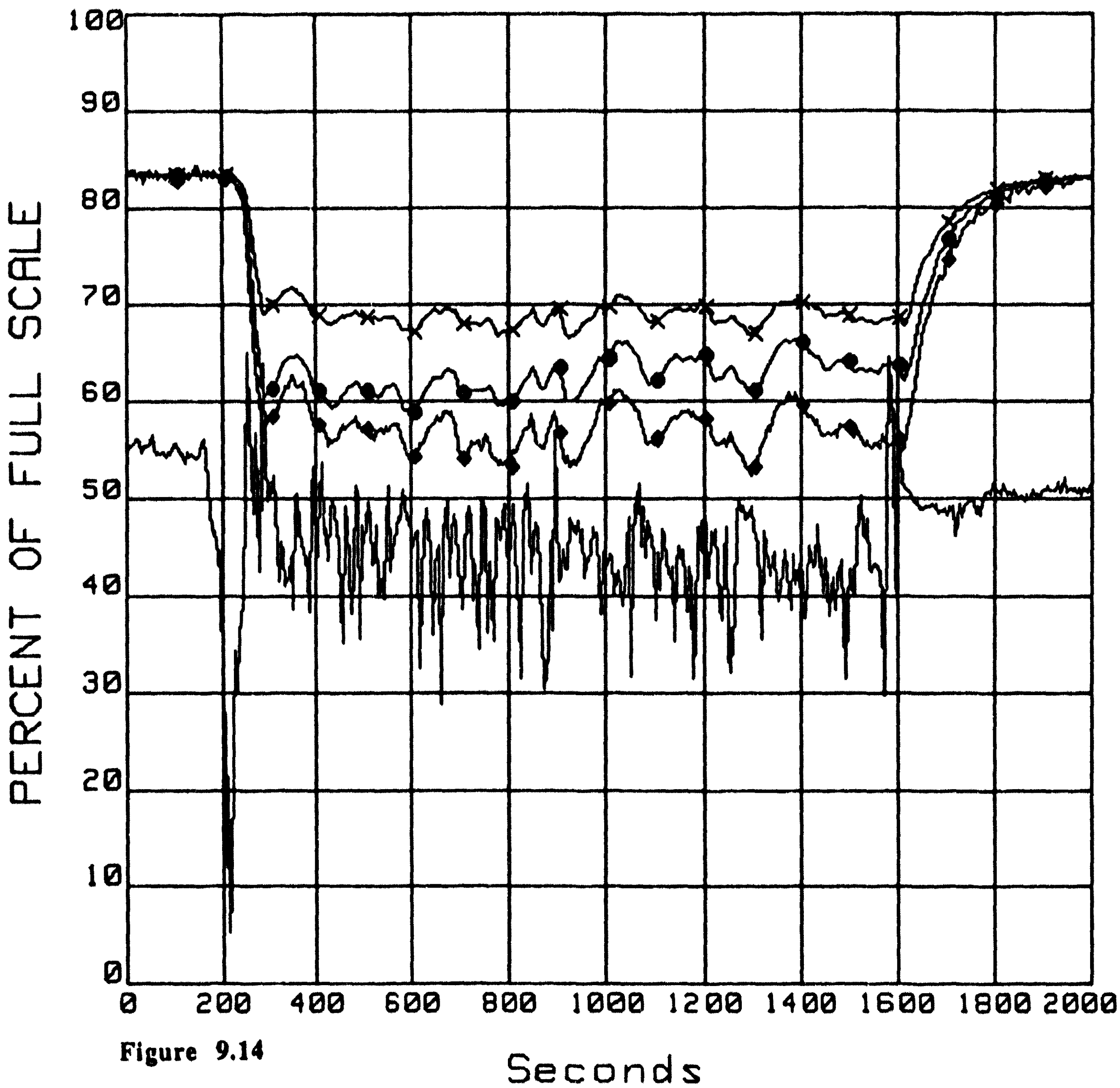


Figure 9.14

Date: 22 Oct 19 Time: 15:29:28

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL10.0	CH-27	Ex Duct Inlet	Degrees Celsius	1000
◆ORNL10.0	CH-28	Ex Duct Elbow Flange	Degrees Celsius	1000
×ORNL10.0	CH-29	Elbow Outside	Degrees Celsius	1000

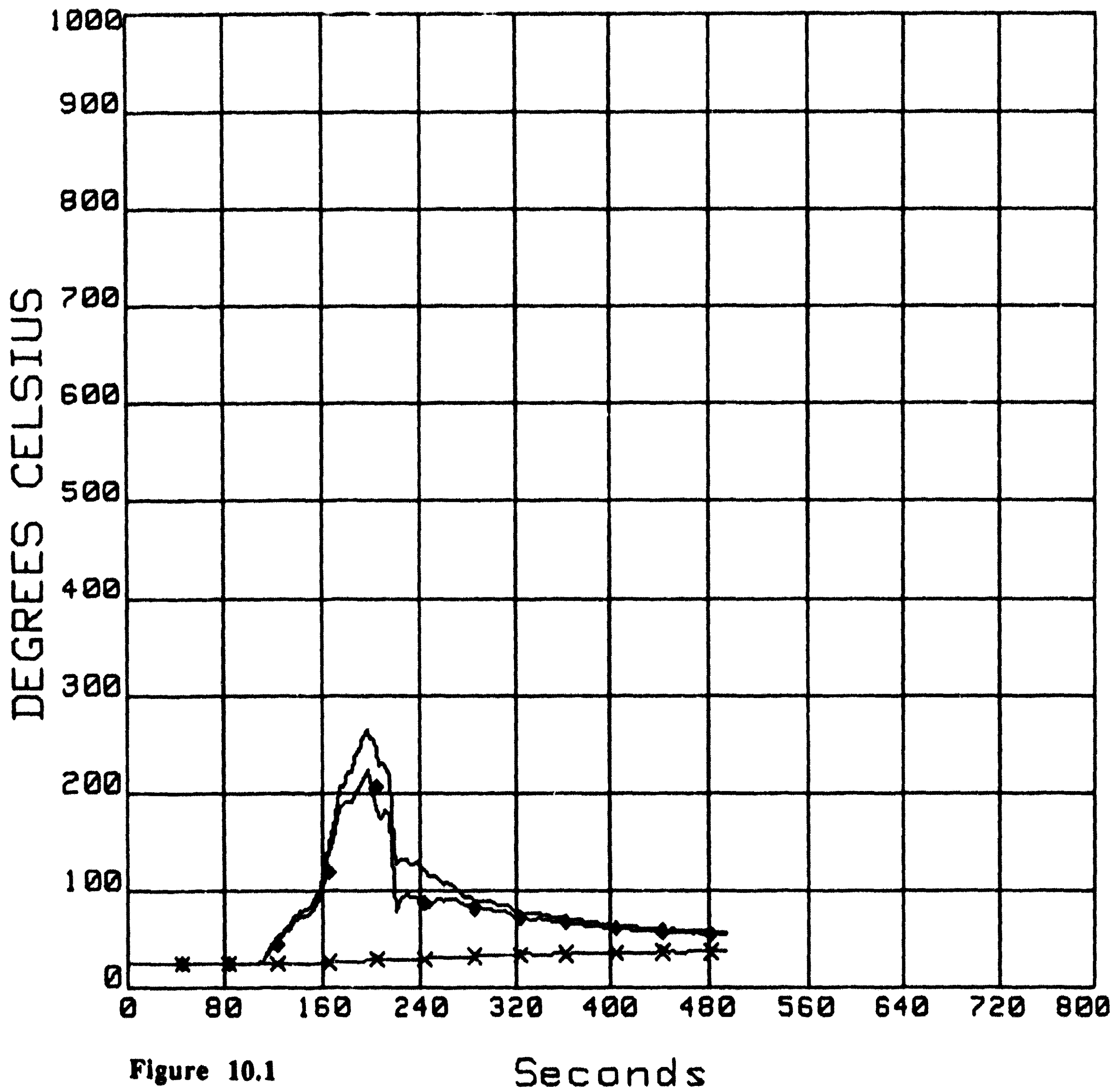


Figure 10.1

Date: 22 Oct 19 Time: 15:29:28

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL10.0	CH-20	So TC RAKE 6" UP	Degrees Celsius	1000
◆ ORNL10.0	CH-21	So TC RAKE 2' UP	Degrees Celsius	1000
× ORNL10.0	CH-22	So TC RAKE 4' UP	Degrees Celsius	1000
● ORNL10.0	CH-23	So TC RAKE 6' UP	Degrees Celsius	1000

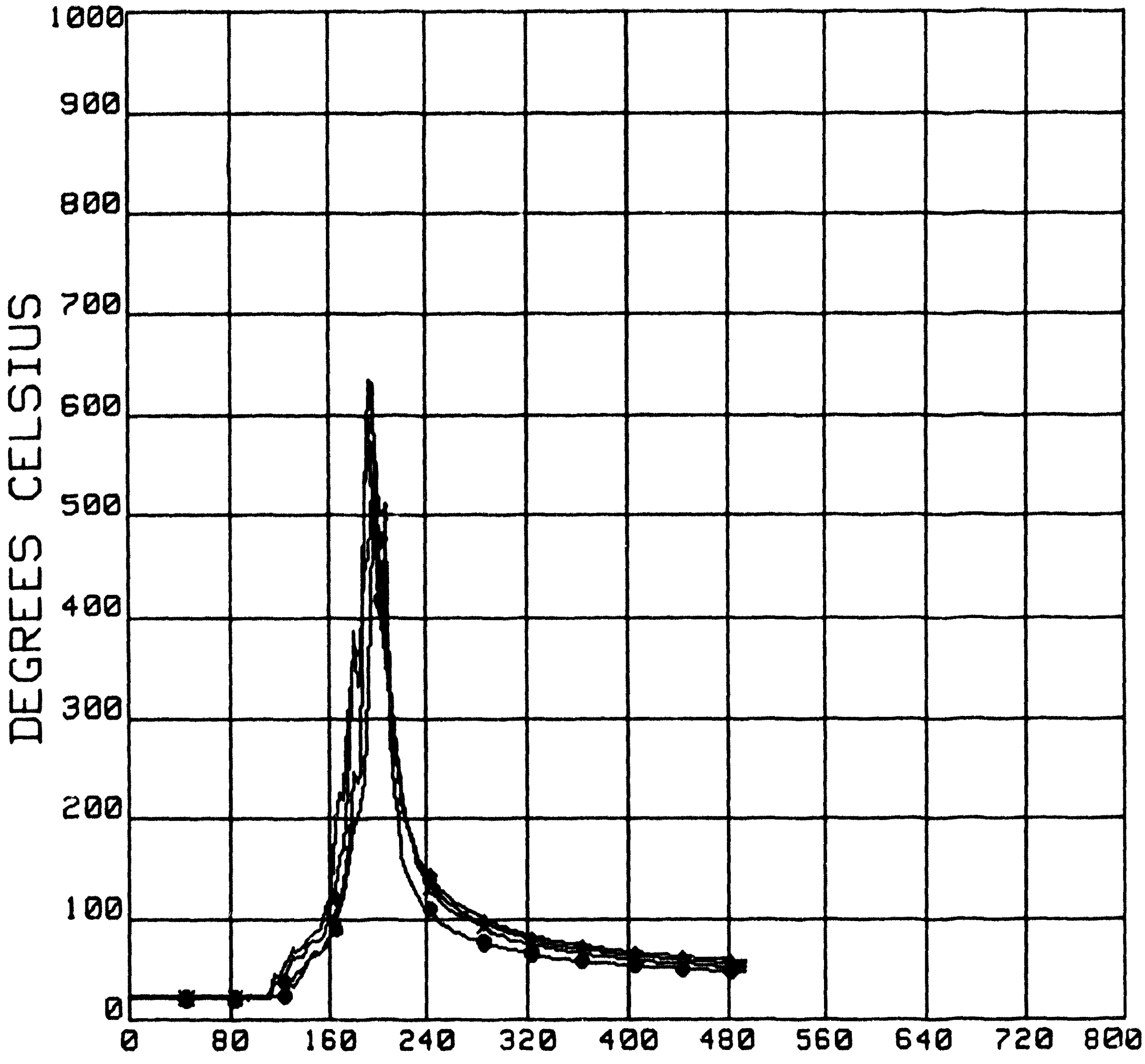


Figure 10.2

Date: 22 Oct 19 Time: 15:29:28

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL10.0	CH-25	TC BY RADIOMETER	Degrees Celsius	1000
◆ ORNL10.0	CH-30	Top Center Room	Degrees Celsius	1000

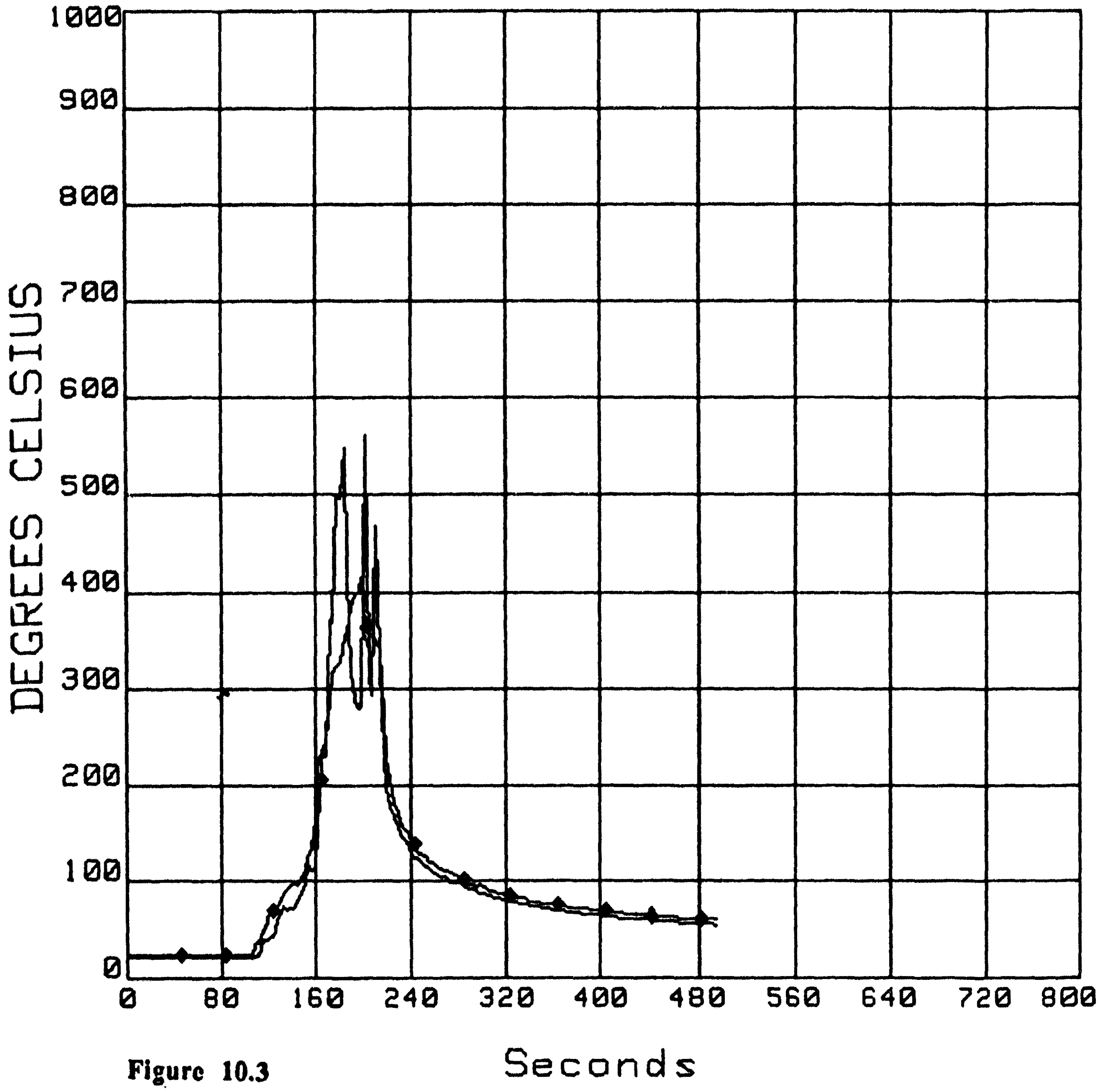


Figure 10.3

Date: 22 Oct 19 Time: 15:29:28

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL10.0	CH-80	O2 6′ UP	% O2	25
◆ ORNL10.0	CH-81	CO2 6′ UP	% CO2	12
× ORNL10.0	CH-82	CO 6′ UP	% CO	1.5
● ORNL10.0	CH-83	HC 6′ UP	PPM (=CH4)	25000

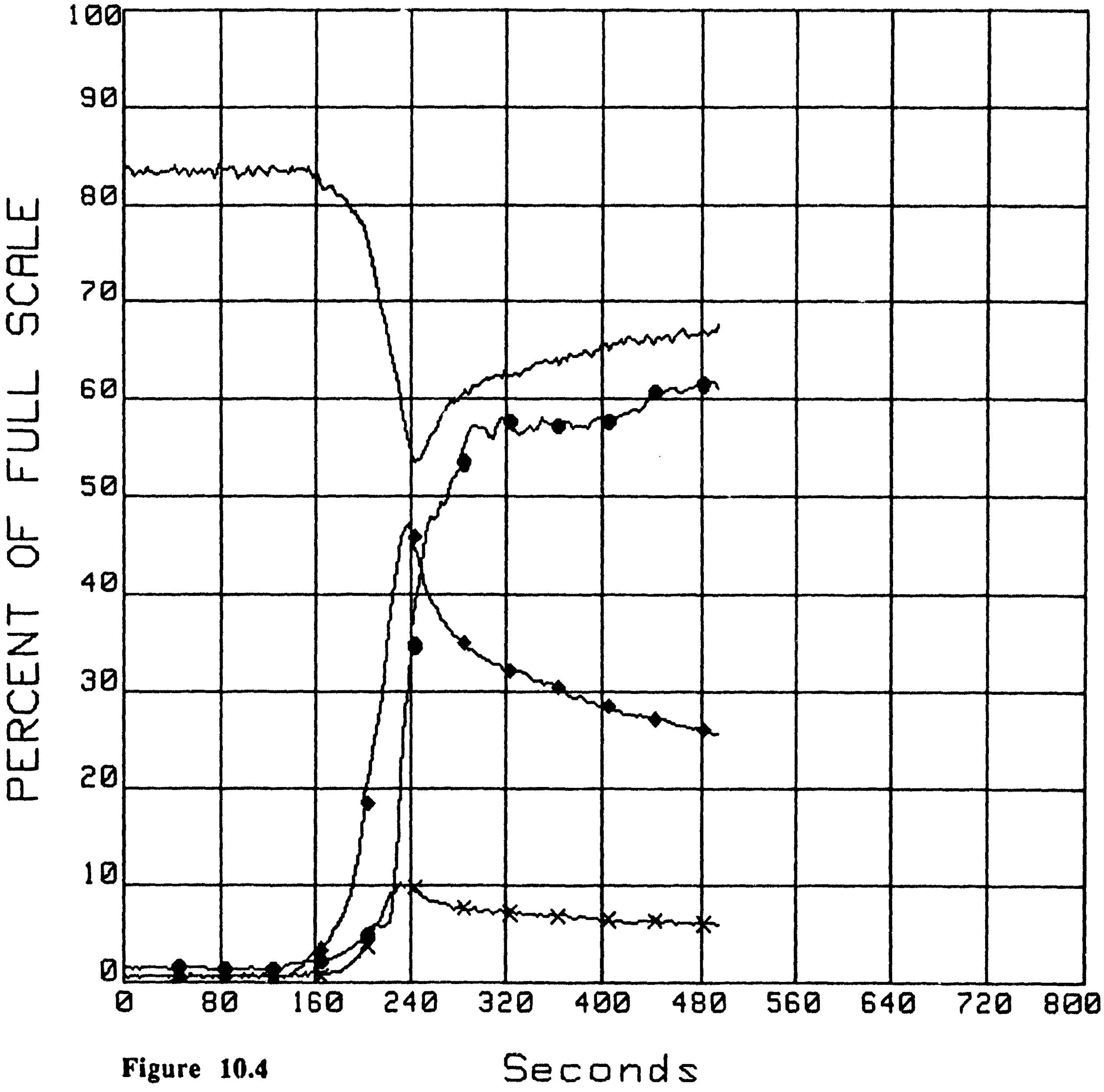


Figure 10.4

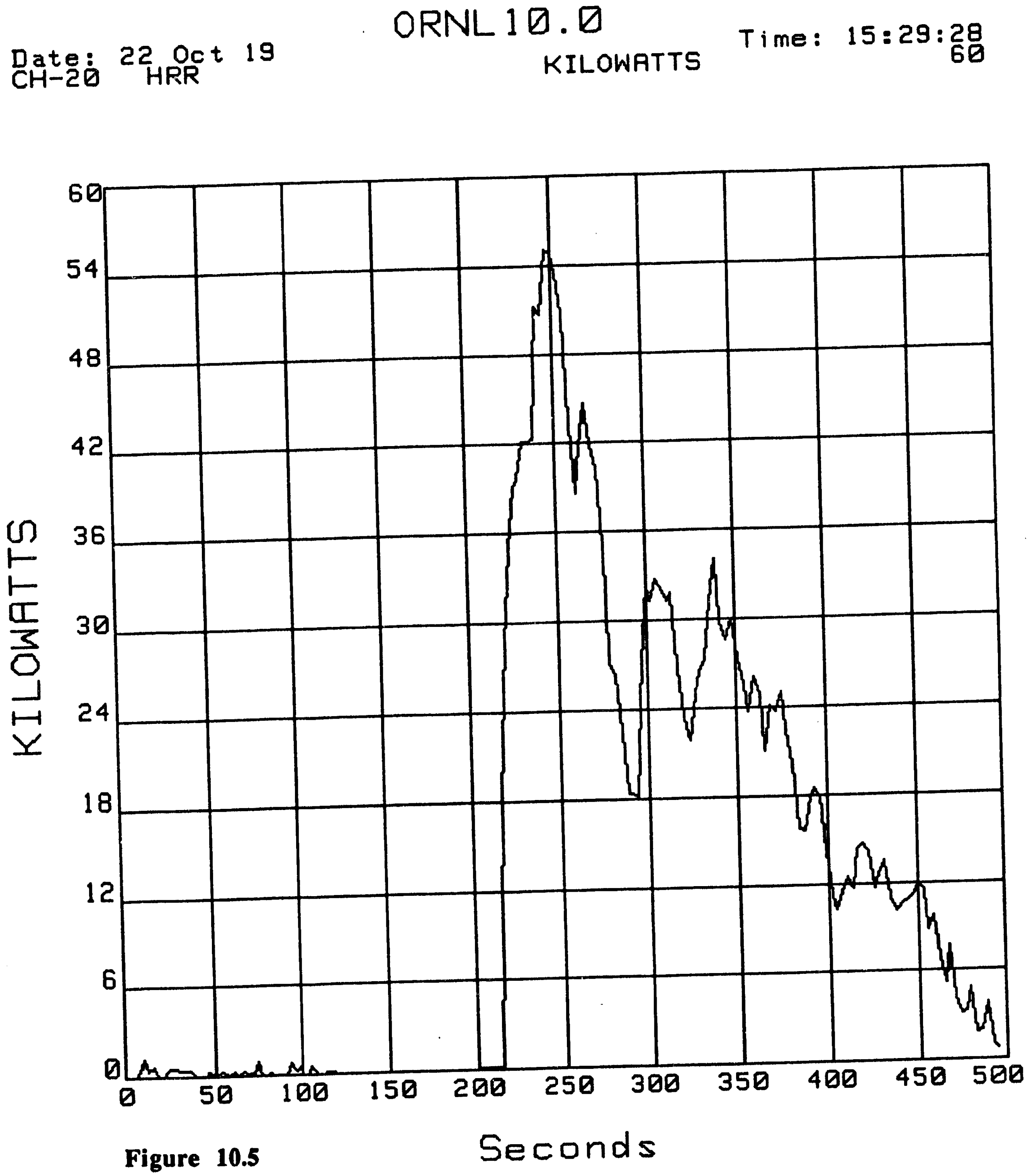


Figure 10.5

No. of channels=38

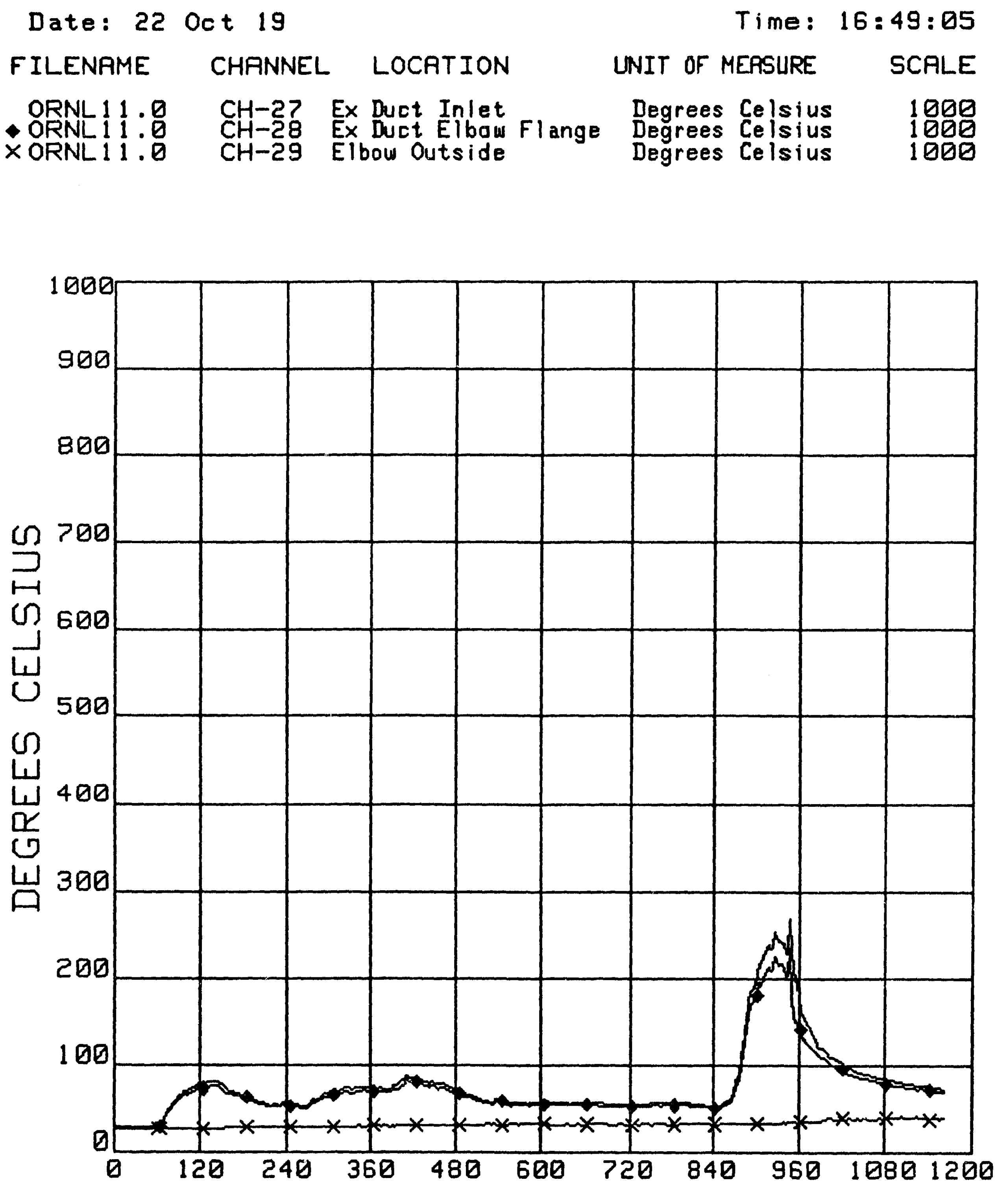

Date: 22 Oct 19
Time: 16:49:05
FILENAME CHANNEL LOCATION UNIT OF MEASURE SCALE
ORNL11.0 CH-27 Ex Duct Inlet Degrees Celsius 1000
◆ ORNL11.0 CH-28 Ex Duct Elbow Flange Degrees Celsius 1000
× ORNL11.0 CH-29 Elbow Outside Degrees Celsius 1000
DEGREES CELSIUS
0
100
200
300
400
500
600
700
800
900
1000
0 120 240 360 480 600 720 840 960 1080 1200
Seconds

Figure 11.1

Date: 22 Oct 19 Time: 16:49:05

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL11.0	CH-20	So TC RAKE 6" UP	Degrees Celsius	1000
◆ ORNL11.0	CH-21	So TC RAKE 2' UP	Degrees Celsius	1000
× ORNL11.0	CH-22	So TC RAKE 4' UP	Degrees Celsius	1000
● ORNL11.0	CH-23	So TC RAKE 6' UP	Degrees Celsius	1000

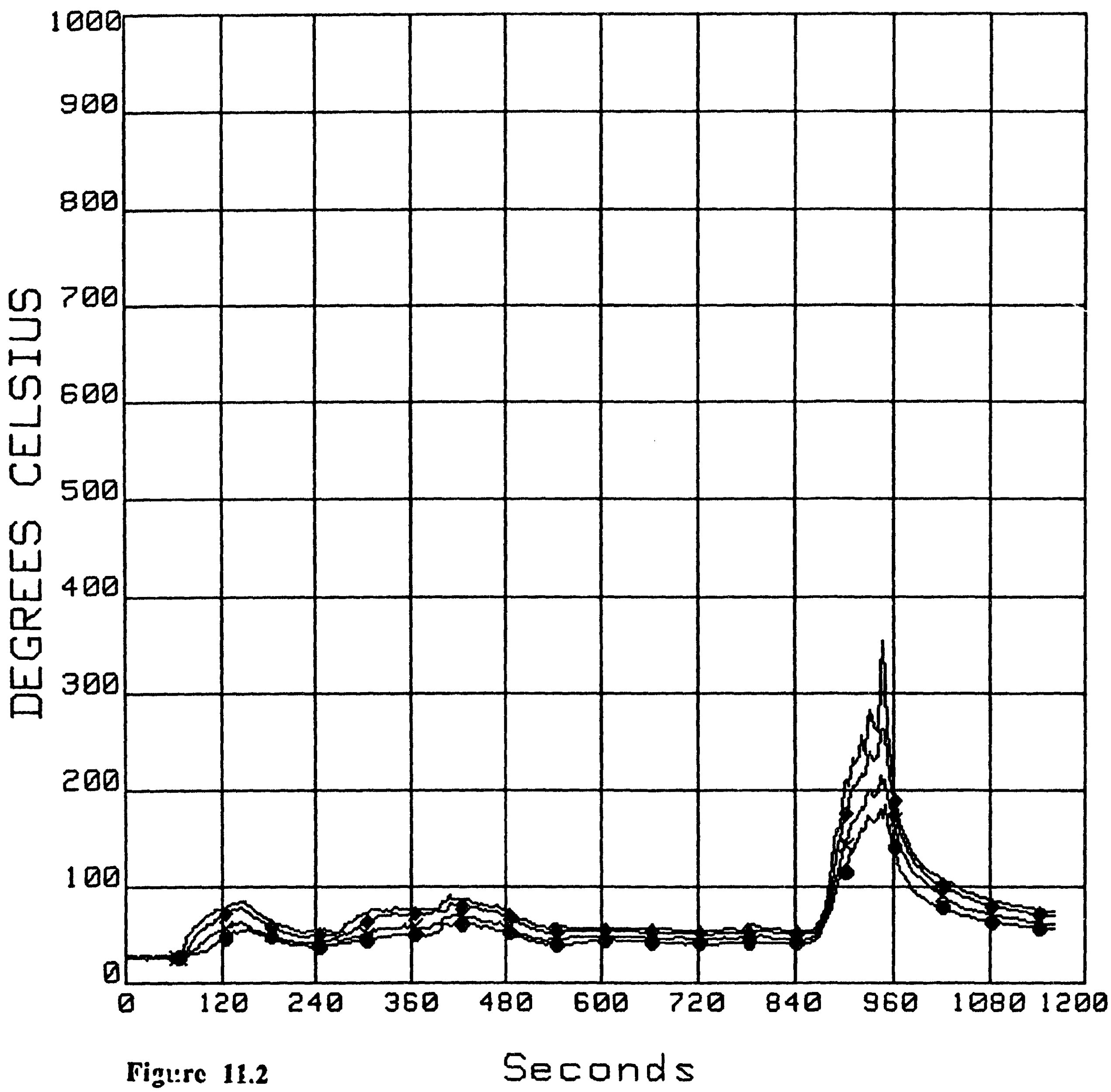


Figure 11.2

Date: 22 Oct 19 Time: 16:49:05

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL11.0	CH-25	TC BY RADIOMETER	Degrees Celsius	1000
◆ ORNL11.0	CH-30	Top Center Room	Degrees Celsius	1000

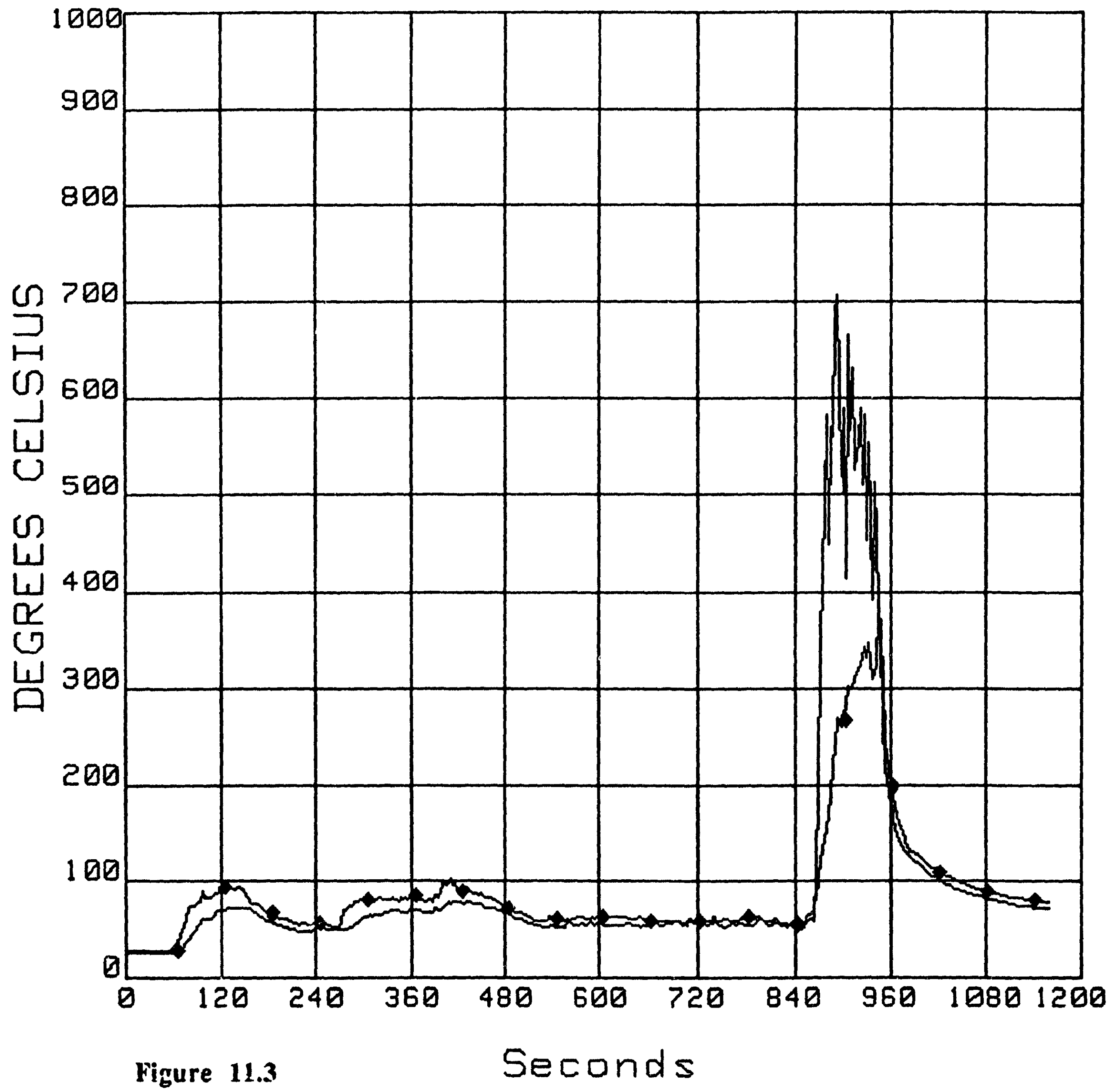


Figure 11.3

Date: 22 Oct 19 Time: 16:49:05

	FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
	ORNL11.0	CH-80	O2 6' UP	% O2	25
◆	ORNL11.0	CH-81	CO2 6' UP	% CO2	12
×	ORNL11.0	CH-82	CO 6' UP	% CO	1.5
●	ORNL11.0	CH-83	HC 6' UP	PPM (=CH4)	25000

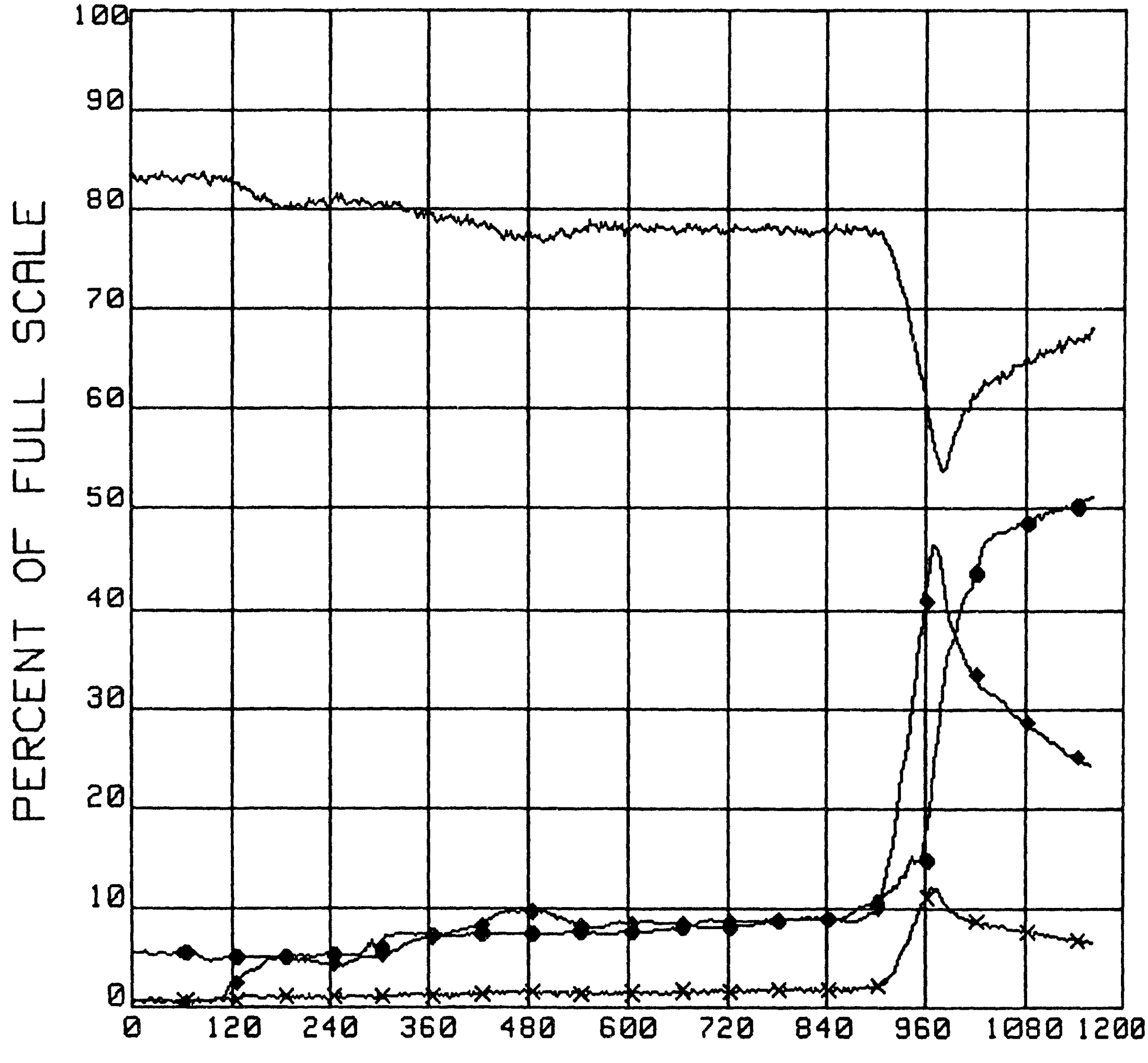


Figure 11.4

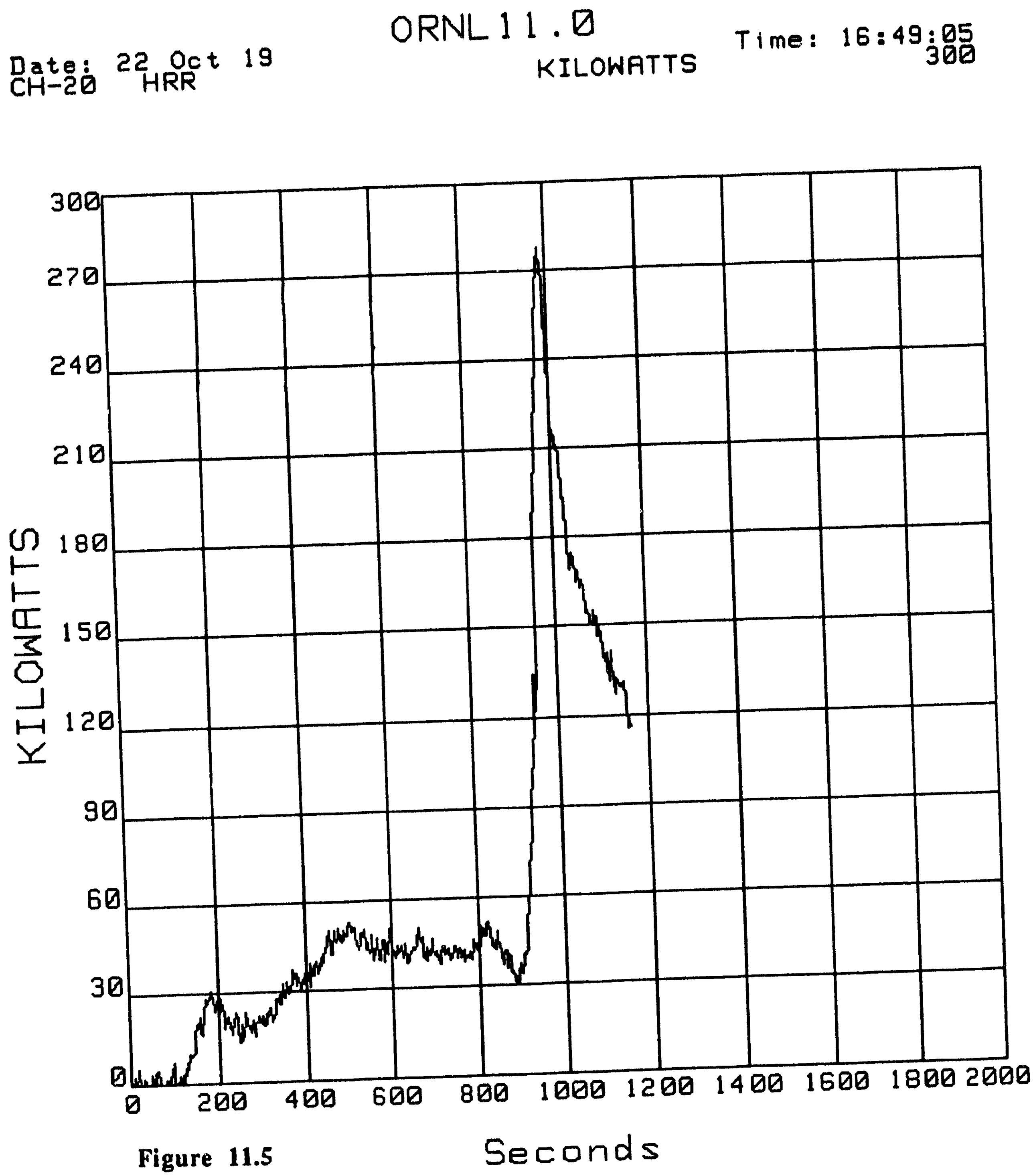


Figure 11.5

No. of channels=38

Date: 26 Oct 19 Time: 09:58:51

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL12.0	CH-27	Ex Duct Inlet	Degrees Celsius	1000
◆ ORNL12.0	CH-28	Ex Duct Elbow Flange	Degrees Celsius	1000
× ORNL12.0	CH-29	Elbow Outside	Degrees Celsius	1000

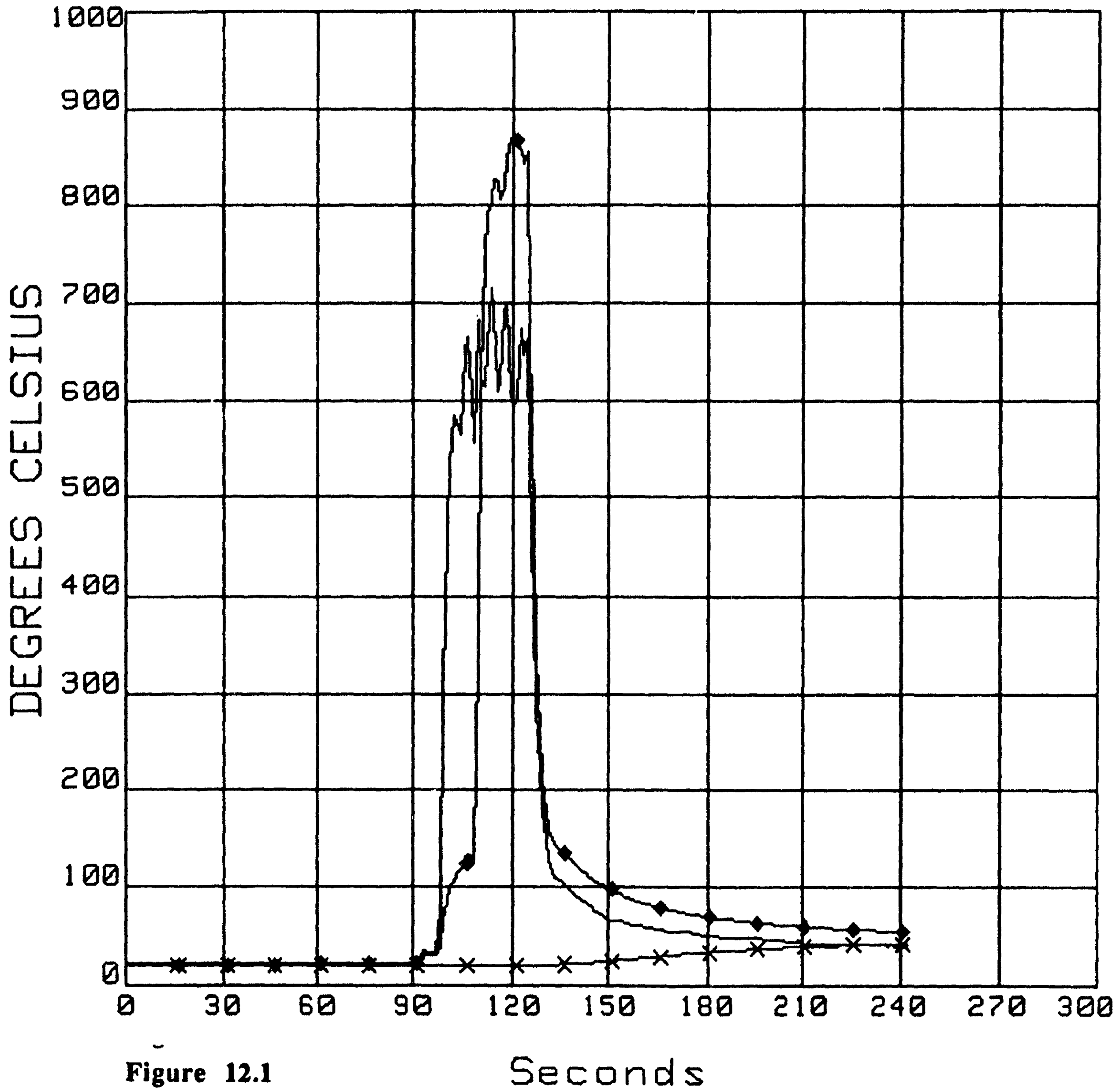


Figure 12.1

Date: 26 Oct 19 Time: 10:30:29

FILENAME	CHANNEL	LOCATION	UNIT OF MEASURE	SCALE
ORNL12.1	CH-27	Ex Duct Inlet	Degrees Celsius	1000
◆ ORNL12.1	CH-28	Ex Duct Elbow Flange	Degrees Celsius	1000
× ORNL12.1	CH-29	Elbow Outside	Degrees Celsius	1000

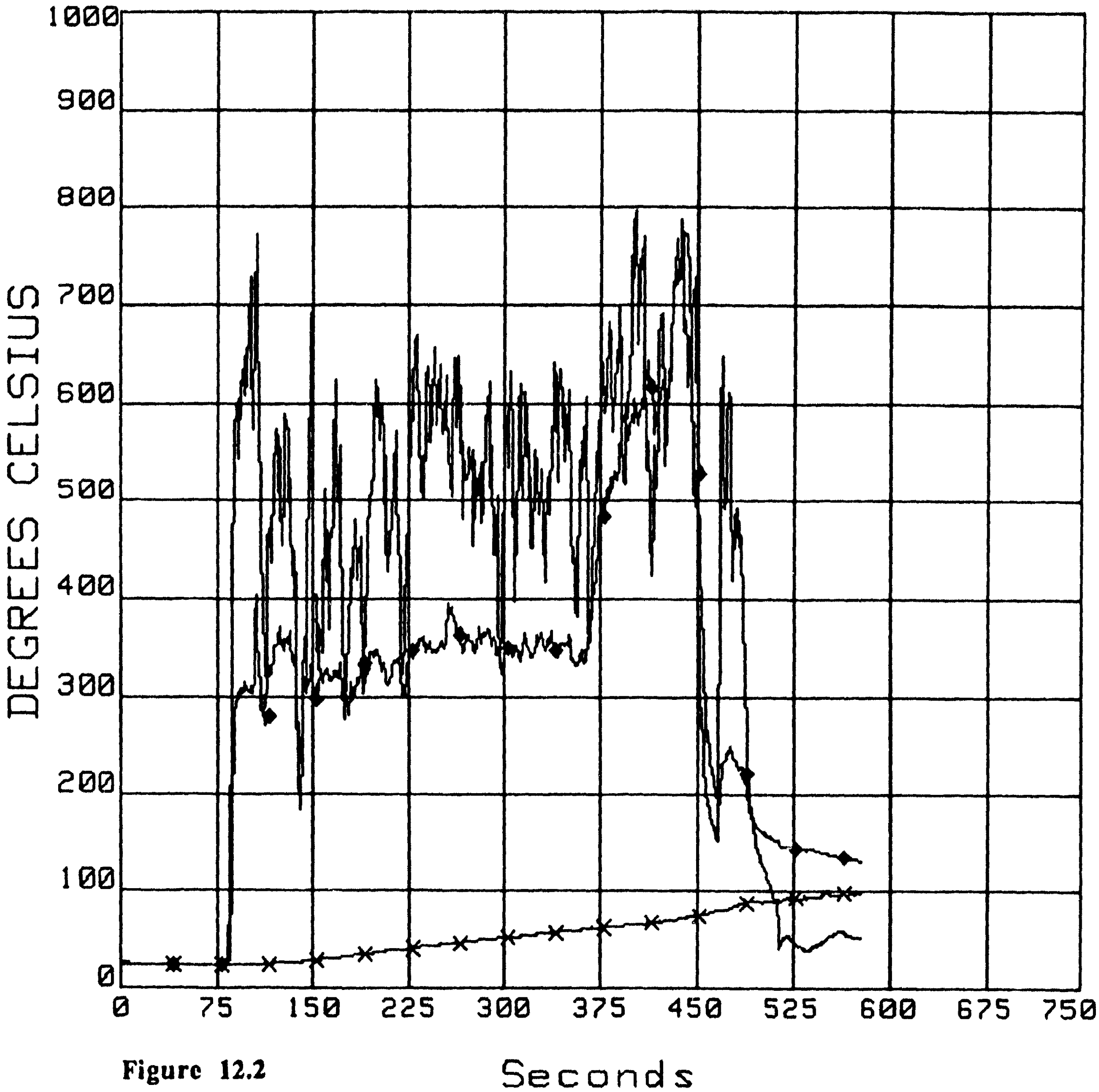


Figure 12.2

DATE FILMED

11/13/94

END