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Task 3.13 - Hot-Gas Filter Testing

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TASK 3.13 – HOT-GAS FILTER TESTING

1.0 OBJECTIVES

The objectives of the hot-gas cleanup (HGC) work on the transport reactor demonstration unit (TRDU) located at the Energy & Environmental Research Center (EERC) is to demonstrate acceptable performance of hot-gas filter elements in a pilot-scale system prior to long-term demonstration tests. The primary focus of the experimental effort in the 3-year project is the testing of hot-gas filter element performance (particulate collection efficiency, filter pressure differential, filter cleanability, and durability) as a function of temperature and filter face velocity during short-term operation (100–200 hours). The filter vessel is used in combination with the TRDU to evaluate the performance of selected hot-gas filter elements under gasification operating conditions. This work directly supports the power systems development facility (PSDF) utilizing the M.W. Kellogg transport reactor located at Wilsonville, Alabama (1) and, indirectly, the Foster Wheeler advanced pressurized fluid-bed combustor, also located at Wilsonville (2).

2.0 BACKGROUND INFORMATION

The U.S. Department of Energy (DOE) Federal Energy Technology Center (FETC) has a HGC program intended to develop and demonstrate gas stream cleanup options for use in combustion- or gasification-based advanced power systems. One objective of the FETC HGC program is to support the development and demonstration of barrier filters to control particulate matter. The goal is not only to meet current New Source Performance Standards (NSPS) with respect to particulate emissions, but also to protect high-efficiency gas turbines and control particulate emissions to low enough levels to meet more stringent regulatory requirements anticipated in the future. DOE FETC is investing significant resources in the PSDF under a Cooperative Agreement with Southern Company Services, Inc. (SCS). The Wilsonville facility will include five modules, including an advanced gasifier module and a HGC module. The gasifier module incorporates the M.W. Kellogg transport reactor technology for both gasification and combustion (3). Several other demonstration-scale advanced power systems also utilizing hot-gas particulate cleanup technology will benefit indirectly from this research. These systems include the Clean Coal IV Piñon Pine IGCC Power Project located at the Sierra Pacific Power Company's Tracy Station near Reno, Nevada.

The TRDU was built and operated at the EERC under Contract No. C-92-000276 with SCS. The M.W. Kellogg Company designed and procured the reactor and provided valuable on-site personnel for start-up and during operation. The Electric Power Research Institute (EPRI) was involved in establishing the program and operating objectives with the EERC project team.

The purpose of the previous program was to build a reactor system larger than the transport reactor test unit (TRTU) located in Houston, Texas, in support of the Wilsonville PSDF transport reactor train. The program was to address design and operation issues for the Wilsonville unit and also help develop information on the operation of the unit to decrease start-up costs.

The TRDU (240-lb/hr coal–limestone feed rate) now provides an intermediate scale to the TRTU (up to 10-lb/hr coal–limestone feed rate) and the Wilsonville Transport Reactor (3400-lb/hr feed rate). Some of the design, construction, start-up, and operational issues for the Wilsonville transport train are being addressed during this project.

The four major design criteria that were established by EPRI were met. These included coal feed rate, operating pressure, carbon conversion, and high heating value of the product gas. Major accomplishments included showing that the TRDU performed well hydrodynamically, that it had the ability to switch from combustion mode to gasification mode easily and safely, that solids could be fed to and removed from the system, and that the J-leg/standpipe and cyclone performed according to their design specifications. The staged char combustion mixing zone design was not verified because of the lack of nonvolatile char and a reduced operational schedule. This resulted in oxygen breakthrough from the mixing section into the riser as a result of insufficient carbon inventory in the circulating solids.

3.0 PROJECT DESCRIPTION

This program has a phased approach involving modification and upgrades to the TRDU and the fabrication, assembly, and operation of a hot-gas filter vessel (HGFV) capable of operating at the outlet design conditions of the TRDU, a 200–300-lb/hr pressurized circulating fluid-bed gasifier similar to the gasifier being tested at the Wilsonville facility. The TRDU has an exit gas temperature of up to 980°C (1800°F), a gas flow rate of 325 scfm, and an operating pressure of 120–150 psig. Phase I included upgrading the TRDU based upon past operating experiences. Additions included a nitrogen supply system upgrade, upgraded LASH (lime ash) auger and coal feed lines, a second pressurized coal feed hopper, the addition of a dipleg ash hopper, and modifications to spoil the performance of the primary cyclone.

The TRDU system can be divided into three sections: the coal feed section, the TRDU, and the product recovery section. The TRDU proper, as shown in Figure 1, (figures are at end of document) consists of a riser reactor with an expanded mixing zone at the bottom, a disengager, and a primary cyclone and standpipe. The standpipe is connected to the mixing section of the riser by a J-leg transfer line. All of the components in the system are refractory-lined and designed mechanically for 150 psig and an internal temperature of 1090°C (2000°F). Table 1 summarizes the operational performance for the TRDU under the previous test program (4).

The premixed coal and limestone feed to the transport reactor can be admitted through three nozzles, which are at varying elevations. Two of these nozzles are located near the top of the mixing zone (gasification), and the remaining one is near the bottom of the mixing zone (combustion). During operation of the TRDU, feed is admitted through only one nozzle at a time.

TABLE 1

TRDU Design and Operational Parameters from Previous Program

Parameter	Design	Actual Operating Conditions[1]
Coal	Illinois No. 6	Wyodak
Moisture Content, %	5	20
Pressure, psig	120	117–122
Steam:Coal Ratio	0.34	0.38
Air:Coal Ratio	4.0	3.5–4.7
Ca:S Ratio, mole	1.5	1.5
Air Inlet Temperature, °C	427	425
Steam Preheat, °C	537	390
Coal Feed Rate, lb/hr	198	173
Gasifier Temperature, maximum °C	1010	850
ΔT, maximum °C	17	121
Conversion, %	>80	96
HHV of Fuel Gas, Btu/scf	100	104
Heat Loss as Coal Feed, %	19.5	14–27
Riser Velocity, ft/sec	31.3	28–30
Heat Loss, Btu/hr	252,000	420,000
Standpipe Superficial Velocity, ft/sec	0.1	0.4–0.54

[1] Steady-state conditions were not achieved.

The coal feed is measured by an rpm controlled metering auger. Oxidant is fed to the reactor through two pairs of nozzles at varying elevations within the mixing zone. For the combustion mode of operation, additional nozzles are provided in the riser for feeding secondary air. Hot solids from the standpipe are circulated into the mixing zone, where they come into contact with the nitrogen and the steam being injected into the J-leg. This feature enables spent char to contact steam prior to the fresh coal feed. This staged gasification process is expected to enhance the process efficiency. Gasification or combustion and desulfurization reactions are carried out in the riser as coal, sorbent, and oxidant (with steam for gasification) flow up the tube. The solids circulation into the mixing zone is controlled by the solids level in the standpipe.

The riser, disengager, standpipe, and cyclones are equipped with several internal and skin thermocouples. Nitrogen-purged pressure taps are also provided to record differential pressure across the riser, disengager, and the cyclones. The data acquisition and control system scans the data points every ½ sec but is only saving the process data every 30 sec. The bulk of entrained solids leaving the riser is separated from the gas stream in the disengager and circulated back to the riser via the standpipe. A solids stream is withdrawn from the standpipe via an auger to maintain the system's solids inventory. Gas exiting the disengager enters a primary cyclone that has been modified to provide variable particulate collection performance. Solids from the primary cyclone are collected in a lock hopper. Gas exiting this cyclone enters a jacketed-pipe heat exchanger before entering the HGC filter vessel. The cleaned gases leaving the HGC filter vessel enter a quench system before being depressurized and vented to a flare.

The quench system uses a sieve tower and two direct-contact water scrubbers to act as heat sinks and remove impurities. All water and organic vapors are condensed in the first scrubber, with the second scrubber capturing entrained material and serving as a backup. The condensed liquid is separated from the gas stream in a cyclone that also serves as a reservoir. Liquid is pumped either to a shell-and-tube heat exchanger for reinjection into the scrubber or down to the product receiver barrels.

3.1 Hot-Gas Filter Vessel

Subtask 3.13 - Hot-Gas Filter Testing was a hot-gas filter program started in January 1995 as an addition to the Morgantown Energy Technology Center (METC) Cooperative Agreement. First-year funding made available in March 1995 supported upgrades to the TRDU, installation of a filter vessel and the associated inlet–outlet piping, and the performance of three 200-hour filter tests. The filter design criteria are summarized in Table 2, and a schematic is given in Figure 2.

This vessel is designed to handle all of the gas flow from the TRDU at its expected operating conditions. The vessel is approximately 48 in. ID and 185 in. long and is designed to handle gas flows of approximately 325 scfm at temperatures up to 980°C (1800°F) and 130 psig. The refractory has a 28-in. ID with a shroud diameter of approximately 22 in. The vessel is sized such that it could handle candle filters up to 1.5 m long; however, 1-m candles are currently being utilized in the initial 540°C (1000°F) gasification tests. Candle filters are 2.375 in. OD with a 4-in. center line-to-center line spacing.

TABLE 2

Design Criteria for the Pilot-Scale Hot-Gas Filter Vessel

Operating Conditions	Design
Inlet Gas Temperature	540°–980°C
Operating Pressure	150 psig
Volumetric Gas Flow	325 scfm
Number of Candles	19 (1 or 1.5 meter)
Candle Spacing	4 in. ℄ to ℄
Filter Face Velocity	2.5–10 ft/min
Particulate Loading	< 10,000 ppm
Temperature Drop Across HGFV	< 30°C
Nitrogen Backpulse System Pressure	up to 800 psig
Backpulse Valve Open Duration	up to 1-s duration

The total number of candles that can be mounted in the current geometry of the HGFV tube sheet is 19. This enables filter face velocities as low as 2.5 ft/min to be tested using 1-m candles. Phases III through V consisted of 200-hr hot-gas filter tests under gasification conditions using the TRDU with the HGC operating at temperatures of 540°-650°C (1000°-1200°F), 120 psig, and increasing face velocities for each test. Higher face velocities would be achieved by using fewer candles. The current test matrix performed the first filter test at 540°-650°C (1000°-1200°F), 120 psig, 2.75 ft/min face velocity. The second test involved removing six candles to increase the face velocity to approximately 4.5 ft/min at the same operating temperature and pressure. The openings for the six removed candles were blanked off. Depending on the approval of the FETC project manager, the third test will involve removing another six candles to achieve a higher face velocity (7.5 ft/min) or investigating other parameters such as primary cyclone spoiling to improve the candle cleaning efficiency. This program is currently testing Industrial Filter & Pump (IF&P) Fibrosic™ candles along with their ceramic tube sheet, silicon carbon-coated ceramic fiber candles from the 3M company, along with sintered metal (iron aluminide) and Vitropore silicon carbon ceramic candles from Pall Advanced Separation Systems Corporation.

Ports were added in the filter vessel to allow temperature and pressure measurements to be obtained and to allow for the insertion of a water-cooled borescope probe for inspecting candle filters off-line. The ash letdown system consists of two sets of alternating high-temperature valves with a conical pressure vessel to act as a lock hopper. Additionally, a preheat natural gas burner attached to a separate gasifier is used to preheat the filter vessel separately from the TRDU while the gasifier is heating up. The hot gas from the burner enters the vessel via a nozzle inlet separate from the dirty gas.

The high-pressure nitrogen backpulse system is capable of backpulsing up to four sets of four or five candle filters with ambient-temperature nitrogen in a time-controlled sequence. The pulse length and volume of nitrogen displaced into the filter vessel is controlled by regulating the pressure (up to 800 psig) of the nitrogen reservoir and the solenoid valves used to control the timing of the gas pulse. Figure 1 also shows the filter vessel location and process piping in the EERC gasifier tower. Since the first three filter tests are to be completed in the 540°-650°C (1000°-1200°F) range, a length of heat exchanger is used to drop the gas temperature to the desired range. Inserting an existing set of high-temperature valves in the fuel gas heat exchanger has allowed bypassing the filter vessel during start-up of the TRDU and switching to the preheated filter vessel when steady-state conditions are achieved. In addition, sample ports both upstream and downstream of the filter vessel have been utilized for obtaining particulate and hazardous air pollutant (HAP) samples.

TRDU operation and filter element testing have benefitted other ongoing projects at the EERC. The same sampling and analysis activities have been conducted to generate HAP data concerning trace metal transformations, speciation of mercury, and metal concentrations at selected points within the TRDU and HGC in support of a project entitled "Trace Element Emissions" funded by METC. In addition, materials and ash data concerning the high-temperature filter media and ash interactions have been collected in support of a project entitled "Hot-Gas Filter Ash Characterization" jointly funded by METC and EPRI. While the cost of this specific data collection will be covered by the individual projects, the synergy that results from the integration of these projects will minimize the cost of collecting this information for all involved projects.

3.2 High-Pressure and High-Temperature Sampling System

The high-pressure and high-temperature sampling system (HPHTSS) was designed and constructed to extract dust-laden flue gas isokinetically from either an oxidizing or reducing environment. The maximum gas temperature at which the sample probe can be operated is specified as 980°C (1800°F) for the HPHTSS. The maximum working pressure of the gas stream for the HPHTSS is specified as 150 psig.

The probe for the HPHTSS is a 3/8-in.-OD and 1/8-in.-ID 304 stainless steel tube. The probe can be used for only one sampling test. The key to the sampling system is the use of a vessel designed to withstand high-pressure and high-temperature conditions to enclose the low-pressure sampling devices.

The vessel was constructed of 5-in. schedule 80 pipe and fitted with raised-face 300-lb flanges. The material used for the HPHTSS pressure vessel was 316L stainless steel. The HPHTSS was designed to house both multicyclone assemblies with backup filter and a backup filter alone.

The principle of operation is to pressurize the outside of the sampling device (i.e., multicyclone assembly or backup filter) with nitrogen at a slightly higher gas pressure than the system pressure of the flue gas. The pressure differential between the nitrogen gas within the pressure vessel and the flue gas within the sampling device is maintained at less than 5 psig.

If the HPHTSS is operating in a reducing environment where the presence of organic vapors is a possibility, the pressure vessel is capable of operating at temperatures as high as 540°C (1000°F) and maintaining nitrogen gas pressures up to 150 psig. This will prevent the heavier organic vapors from condensing while passing through the particulate sampling assembly. Electric resistance heaters will be used to heat the pressure vessel to specified temperatures. This operating temperature also allows vapor-phase trace species to be maintained in the vapor phase through the backup filter.

Once the process gas exits the sampling assembly, the gas pressure is reduced through a throttling valve to approximately atmospheric pressure. The throttling valve will also act as the flow control valve for the sampling system. A second throttling valve was installed in series in the event that the primary throttling valve fails to close.

After the throttling valve, the process gas is cooled through a set of impingers to remove moisture and organic vapors if present. A set of up to six impingers may be used in this sampling system. These impingers are rated for 200 psig at 120°C (250°F) maximum operating conditions. The impingers are made of 304 stainless steel, with the interior surfaces coated with Teflon. The Teflon-coated surfaces allow the HPHTSS to be used for collecting the vapor-phase trace metal species.

The dry gas is then metered through a rotameter and dry-gas meter to measure total flow before it is vented out of the stack.

4.0 ACCOMPLISHMENTS

Two test campaigns were conducted during the weeks of October 21–24, 1996, and November 12–16, 1996. During these weeks, approximately 105 hours of coal feed and 94 hours of gasification were achieved, with the system gases and fly ash passing through the filter vessel during the whole test campaign.

4.1 TRDU Operation

The TRDU was operated at relatively low average temperatures of 825°C to alleviate some deposition problems seen in the riser and disengager in previous tests. Table 3 summarizes the operational performance for the TRDU during the last test period. Coal feed rates averaged 266 lb/hr, and the gasifier pressure averaged 120 psig. The dry product gas produced averaged 6.9% CO, 7.9% H_2, 10.7% CO_2, 1.5% CH_4, with the balance being N_2 and other trace constituents. The moisture in the fuel gas averaged 17%. The H_2S concentration started at approximately 1400 ppm and dropped to under 800 ppm over the duration of the test. Calculated recirculation rates started at approximately 5000 lb/hr and slowly increased to approximately 6000 lb/hr at the end of the test. Relative bed density dropped from 100% for a 100% silica sand bed to approximately 50% with the high-carbon and coal ash bed. The bed particle size remained relatively constant over the duration of the test at 200 to 225 μm. Primary cyclone ash was becoming progressively finer during the test. Figures 3 and 4 show the particle distributions of the bed material and primary cyclone ash as they varied with time. Figures 5 and 6 show the bulk ash chemistry of the bed material and the primary cyclone ash as functions of time. Based on silica and calcium balances, it appears the bed material was approximately 50 to 60 wt% converted over to bed ash in 68 hours, while the primary cyclone was essentially all coal ash after 1 day of operation. Primary cyclone ash was recycled to the mixing zone only when the calculated standpipe bed height became less than 5 feet. Returning all of this ash and removing LASH from the standpipe would hasten the bed changeover seen in the TRDU.

4.2 Hot-Gas Filter Vessel Operation

Figures 7 through 10 show the 24-hour temperature history of the HGFV during its 4 days of operation in Test P050. As shown in these figures, the filter temperature started out at the desired temperature (540°C). However, over the next 2 days, the temperature fell below the desired operating temperature and efforts to increase temperature only aggravated the problem by putting the heat exchanger into a film boiling mode which improved the heat transfer coefficient. Finally, in Day 3, the heat exchanger was switched from water to air-cooling. This resulted in a 100°C step change in the HGFV operating temperature with a corresponding increase in filter face velocity from 4.15 to 4.75 ft/min.

Figures 11 through 14 show the pressure history of the filter vessel outlet static and differential, ash hopper, and backpulse reservoir. The candles were backpulsed 390 times during Test P050 before one candle had a major failure. As can be seen in the backpulse signature, the filter vessel was backpulsed at 30 to 40 in. H_2O above the just-cleaned baseline. As the baseline climbed initially from 30 to 60 in. H_2O, the filter vessel differential pressure trigger was increased from 60 to 100 in. H_2O. However, the backpulsing cycle time decreased to approximately every 10 minutes. Changes in the backpulse operating conditions show up in the

TABLE 3

TRDU Average Operating Conditions for Test P050

Parameter	P050
Conditions	Gasification
Coal	Wyodak
Moisture Content, %	23.3
Pressure, psig	120
Steam:Coal Ratio	0.26
Air:Coal Ratio	2.67
Ca:S Ratio, mole	4.7
Coal Feed Rate, lb/hr	266
Mixing Zone, °C , avg. (min.) (max.)	834 (765) (886)
Riser, °C , avg. (min.) (max.)	812 (786) (876)
Standpipe, °C , avg. (min.) (max.)	709 (624) (751)
Conversion, %, (excluding dipleg)	90 (97)
Carbon in Bed, %, Standpipe (dipleg)	22.3 (36.5)
Riser Velocity, ft/s	35.3
Standpipe Velocity, ft/s	0.21
Circulation Rate, kg/hr	5640
Duration, hr	68
Time	07:00–03:00
Date	11-13 to 11-16

[1] Not determined.

pressure traces as either a step change in the reservoir peak pressure (i.e., an increase in reservoir pressure) or a drop in the minimum reservoir pressure (i.e., an increase in the pulse duration). Backpulse operating parameters initially were a 165 psig reservoir pressure with a ¼-sec pulse duration which was increased to 185, 215, and 240 psig with pulse durations of either ½ and ¾ sec. Appendix A summarizes the major changes in the filter vessel or backpulse operating conditions. An increase in pulse duration did not appear to provide any improved backpulse performance; however, an increased backpulse reservoir pressure did appear to provide a small (~1-min.) decrease in the backpulsing frequency but did not lower the "cleaned" baseline differential pressure. The mechanical operation of the N_2 backpulse system and the filter vessel ash letdown system presented no operational problems.

The candles were backpulsed 390 times during Test P050 before one candle had a major failure. The only observed problems were that six of the candles did not seal in the tube sheet correctly. The leakage around the candles is partially the result of mixing four different candle types in a tube sheet with a common holddown plate. The tube sheet and holddown plate were specifically designed for the square-flanged IF&P Fibrosic™ candles. Pall's metal iron aluminide candle had its flange machined to match that of the IF&P candles; however, the Pall Vitropore and the 3M candles were installed using specially machined stainless steel adaptors to convert their hemispherical flange design to match that of the square-flanged tube sheet, resulting in slightly uneven candle flange heights. In addition, the gas inlet temperature was lower than the desired inlet temperature of 540°C until the heat exchanger was switched to air cooling. The average particulate loading going into the HGFV was 3600 ppm, with a d_{50} of 9 μm, while the outlet loading was 77 ppm and increased to 400 ppm after the step change in the filter temperature and face velocity occurred. Figure 15 shows the particle size distribution of the bulk filter ash which has been backpulsed from the candles. As can be seen, the filter ash is approximately the same size (7 to 8 μm) as the ash from the particulate samples. Generally, the filter ash from combustion systems is much larger than the entrained ash collected in particulate samples because the ash has had a chance to agglomerate on the surface of the filter. Figure 16 shows the chemical composition of the major species of the filter ash collected throughout Test P050. This figure shows that in less than 12 hours after entering gasification, the filter ash is steady-state coal ash and does not change with increasing operating time or changing bed chemistry. This filter ash averaged 55 wt% carbon and had a low bulk density of approximately 20 lb/ft^3. The small size, the lack of the cohesiveness seen in other filter ashes, and the low density of the ash suggests that a high percentage of the filter cake will be reentrained back onto the filters after they are backpulsed.

The data acquisition system on the TRDU has been programmed to save the filter vessel differential pressure and the filter outlet static pressure every 2 sec whenever a backpulse sequence is started until 30 sec after the last manifold is backpulsed. Figures 17 and 18 show these data for two backpulse sequences for the same set of backpulse conditions (90 in. trigger, 215 psig, and ¾-sec pulse duration) except that the Figure 18 is associated with a backpulse which occurred after the product gas heat exchanger was switched to air-cooling. This 140°C degree rise in the filter vessel operating temperature also resulted in a 0.6 ft/min (from 4.15 to 4.75 ft/min) rise in the face velocity. Comparing the slopes of the initial rate of filter differential pressure recovery between these two figures indicates that there was much more particulate reentrainment with a relatively modest increase in face velocity. Figure 19 shows the same two pressure traces for a 100 in. H_2O trigger, ½-sec pulse duration, and a 240-psig backpulse reservoir pressure. Figures 20 and 21 show these pressure traces for the same set of operating conditions on the backpulse immediately before and during which the candle broke. The slightly lower peak outlet static pressure which occurred during the backpulsing of the third manifold might be an indication that the candle filter was about to break. Figure 22 is a photograph of the candle's removal from the filter vessel including the broken candle shown in the foreground. This candle broke because of a nominal 2- by 4-in. hole blown out of the side of the candle approximately 6 in. below the tube sheet. Based on other experiences with this candle, the ability of this candle to withstand gasification's reducing environment is uncertain. These candles will be removed from the next gasification test and replaced with another vendor's candles.

TABLE 4

Average Operating Conditions for the Pilot-Scale Hot-Gas Filter Vessel

Operating Conditions		
Heat Exchanger Cooling Media	Water-Cooled	Air-Cooled
Inlet Gas Temperature, °C	513–450	580
Operating Pressure, psig	120	120
Volumetric Gas Flow, scfm	360	400
Number of Candles	13 (1 m)	13 (1 m)
Candle Spacing, in. ℄ to ℄	4	4
Filter Face Velocity, ft/min	4.25	4.75
Particulate Loading, ppm	3200	4000
Temperature Drop Across HGFV, °C	26	25 to 40
Nitrogen Backpulse System Pressure, psig	165, 185, and 215	215 and 240
Backpulse Valve Open Duration, sec	½ and ¾	½

5.0 CONCLUSIONS AND FUTURE PLANS

In conclusion, the TRDU and hot-gas filters operated continuously for 68 hours in gasification mode with no major system upsets. A candle failure after 68 hours of gasification prematurely ended the scheduled 200-hr test. The TRDU average gasifier temperature was a relatively low 825°C to alleviate some deposition seen in previous tests. No deposition was observed in these lower-temperature tests. The candles were backpulsed 390 times during Test P050 before one candle had a major failure. The baseline "cleaned" filter differential pressure increased from 30 to 60 in. H_2O over the course of the test. The particulate inlet was approximately 3500 ppm with the filter ash averaging 55 wt% carbon. The filter ash particle size was approximately 7 μm in size and was essentially representative of the coal ash from very early in the gasification test. The short backpulse intervals of approximately 10 minutes and the initial rapid recovery of the filter differential pressure along with the small size, the lack of the cohesiveness seen in other filter ashes, and the low density of the ash suggests that a high percentage of the filter cake will be reentrained back on to the filters after they are backpulsed.

Future tests should probably not try to increase face velocity (which would compound the ash reentrainment problem) but should maintain the same face velocity with significant spoiling of the primary cyclone to increase the particle-size distribution of the ash entering the filter vessel. In addition, off-line cleaning of the filter vessel should be attempted to determine if the lack of gas flowing through the filter significantly decreases particle reentrainment and can decrease the pulse frequency.

6.0 REFERENCES

1. Ness, R.O. "Transport Reactor Demonstration Unit," *In* Proceedings of the Coal-Fired Power Systems '93 - Advances in IGCC and PFBC Review Meeting; DOE/METC-93/6131 (DE93000289), June 1993; pp 357–358.

2. Rush, R.E.; Moore, D.L.; Haq, Z.U.; Pinkston, T.E.; Vimalchand, P.; McClung, J.D.; Quandt, M.T. "Status of the Advanced PFBC at the Power Systems Development Facility," *In* Proceedings of the Coal-Fired Power Systems '94 - Advances in IGCC and PFBC Review Meeting; DOE/METC-94/1008 (DE94012252), June 1994; Vol. 1, pp 127–137.

3. Rush, R.E.; Hendrix, H.L.; Moore, D.L.; Pinkston, T.E.; Vimalchand, P.; Wheeldon, J.M. "Power Systems Development Facility Progress Report," *In* Proceedings of the Advanced Coal-Fired Power Systems '95 Review Meeting, DOE/METC-95/1018, June 1995, Vol. 1 (DE95009732), pp 23-31.

4. Ness, R.O. "Transport Reactor Demonstration Unit, Volume 1 - Final Report," EERC Publication No. 95-EERC-02-06, May 1995; 150 p.

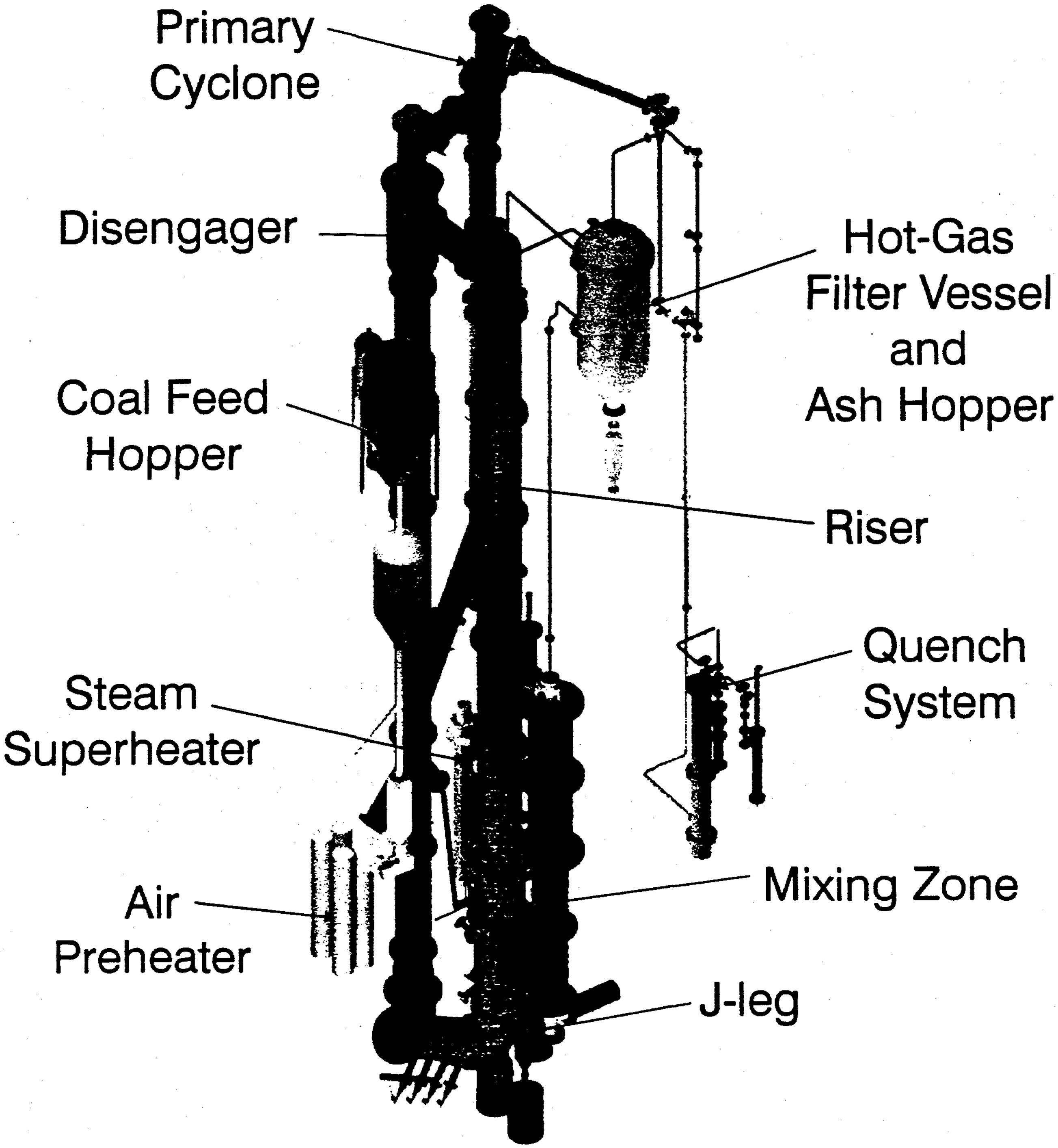

Figure 1. TRDU and hot-gas vessel in the EERC gasification tower.

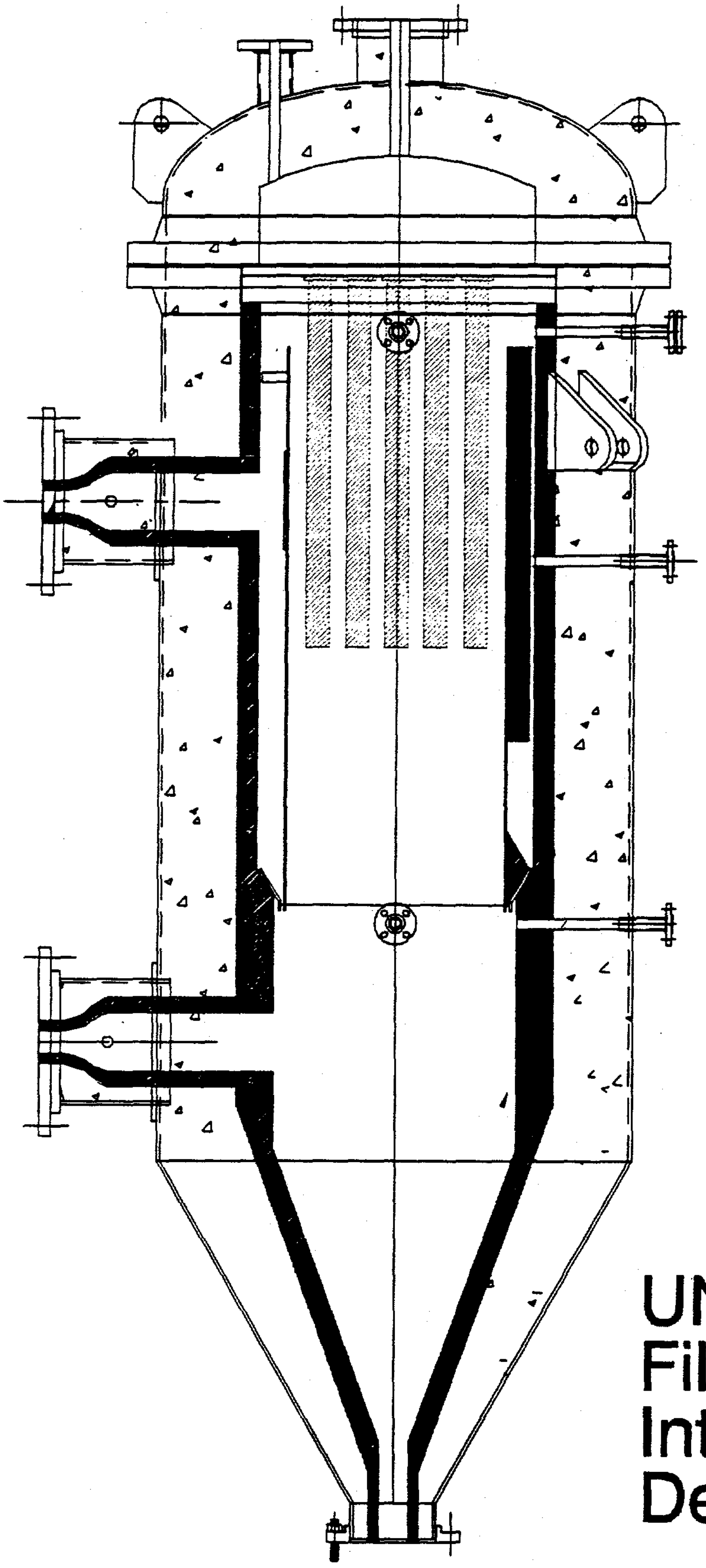

Figure 2. Schematic of the filter vessel design with internal refractory, tube sheet, and shroud.

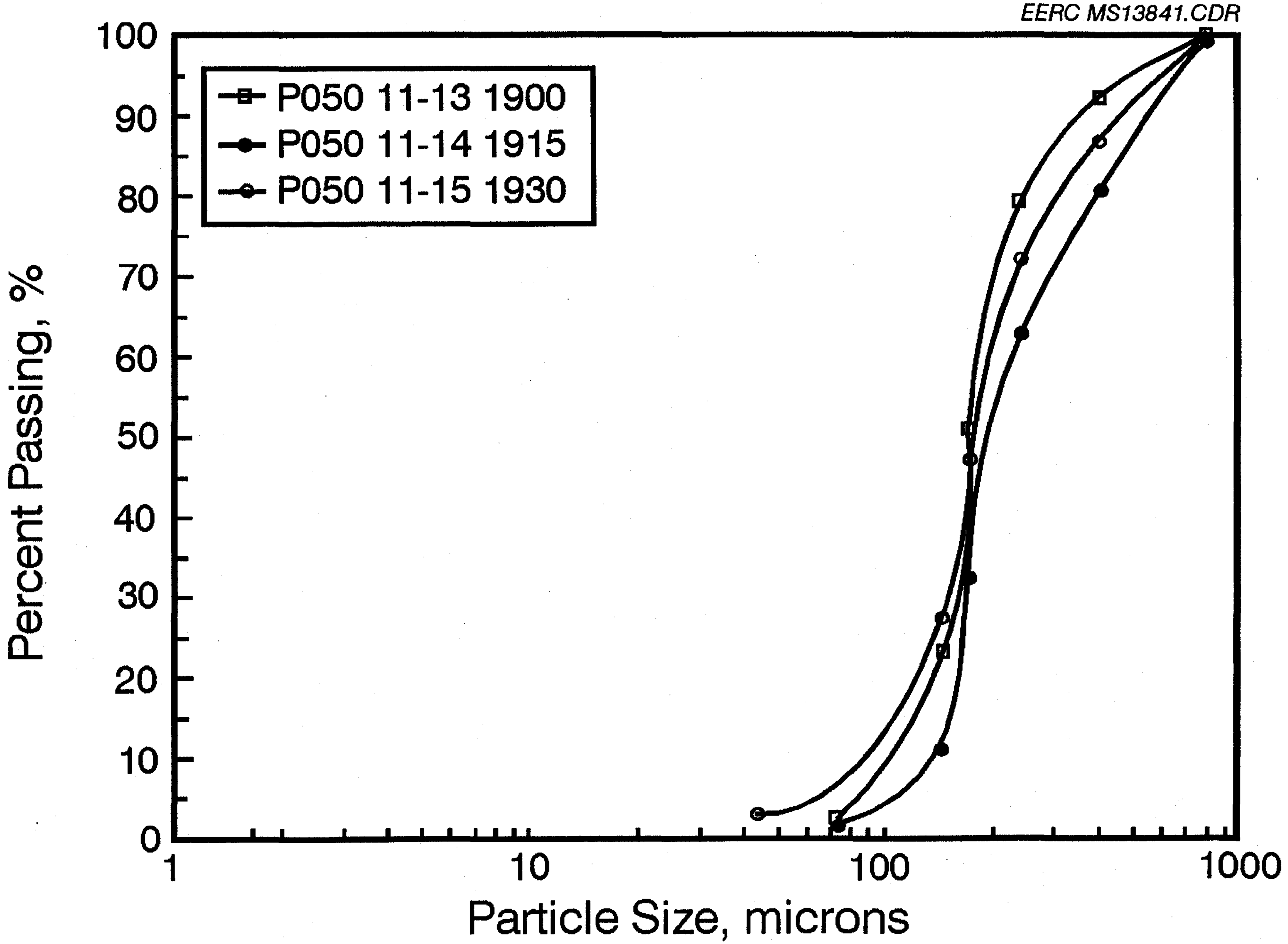

Figure 3. Particle-size distribution of bed material during Test P050.

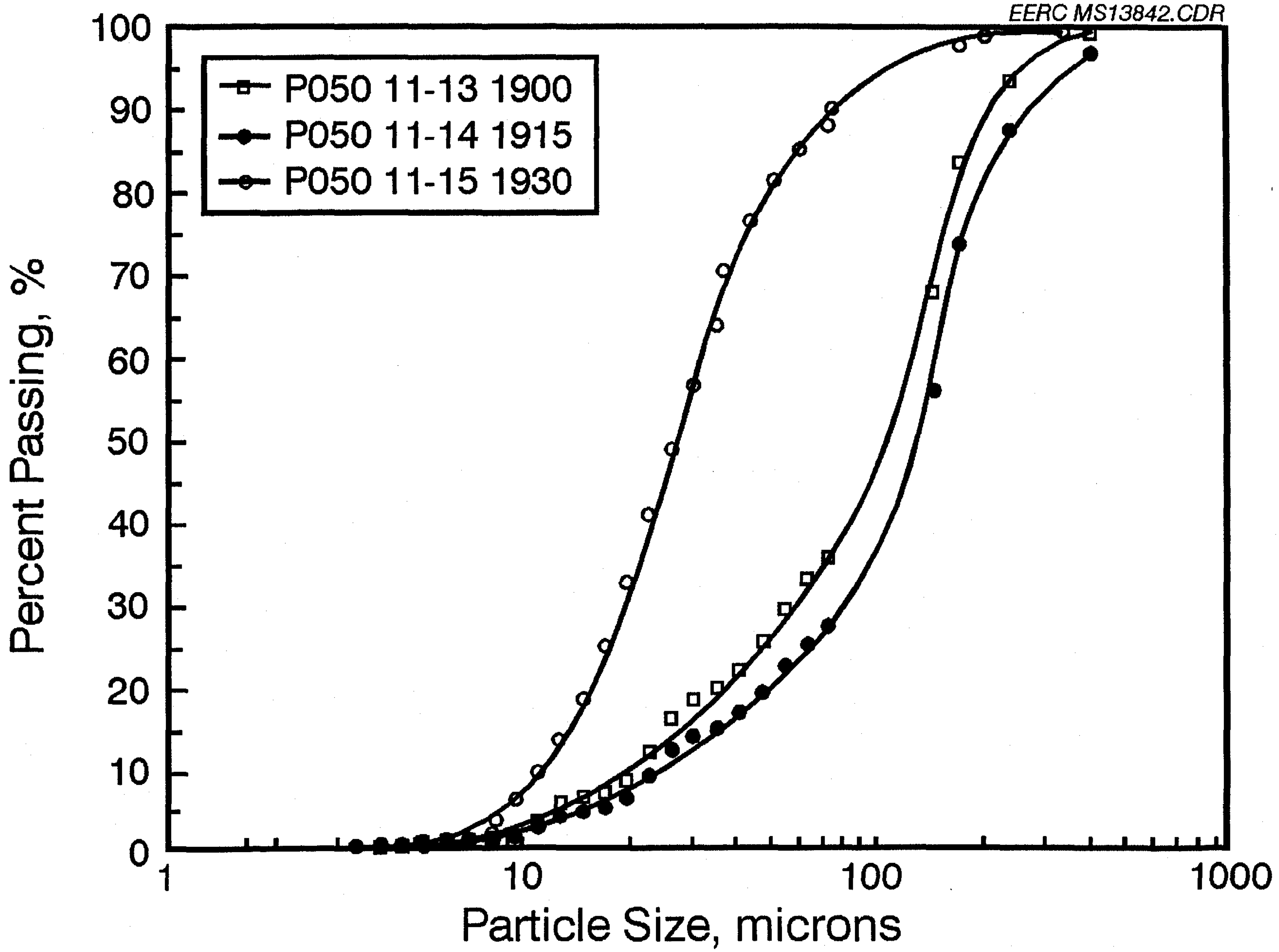

Figure 4. Particle-size distribution of primary cyclone ash during Test P050.

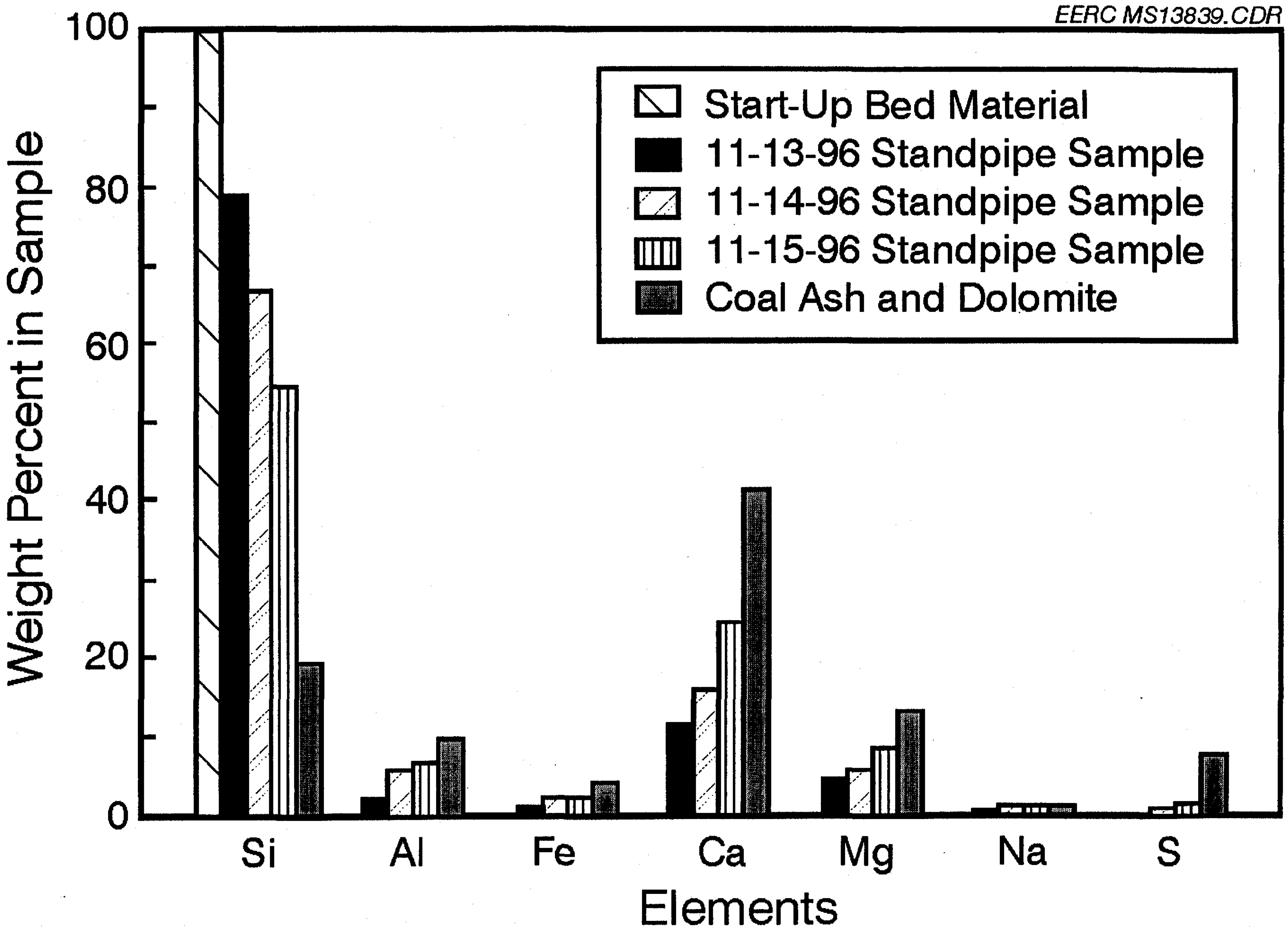

Figure 5. Chemical composition of bed material during Test P050.

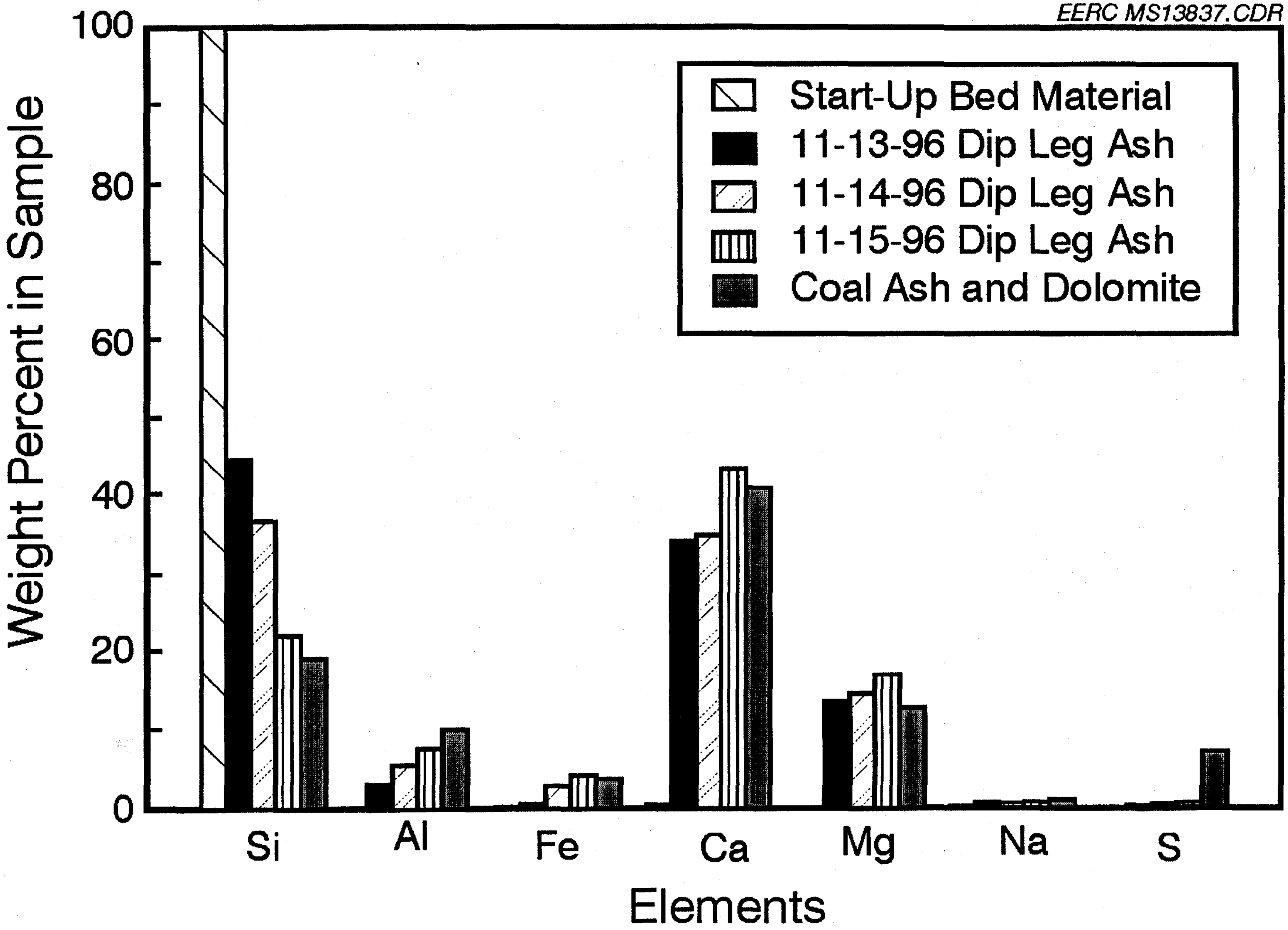

Figure 6. Chemical composition of primary cyclone ash during Test P050.

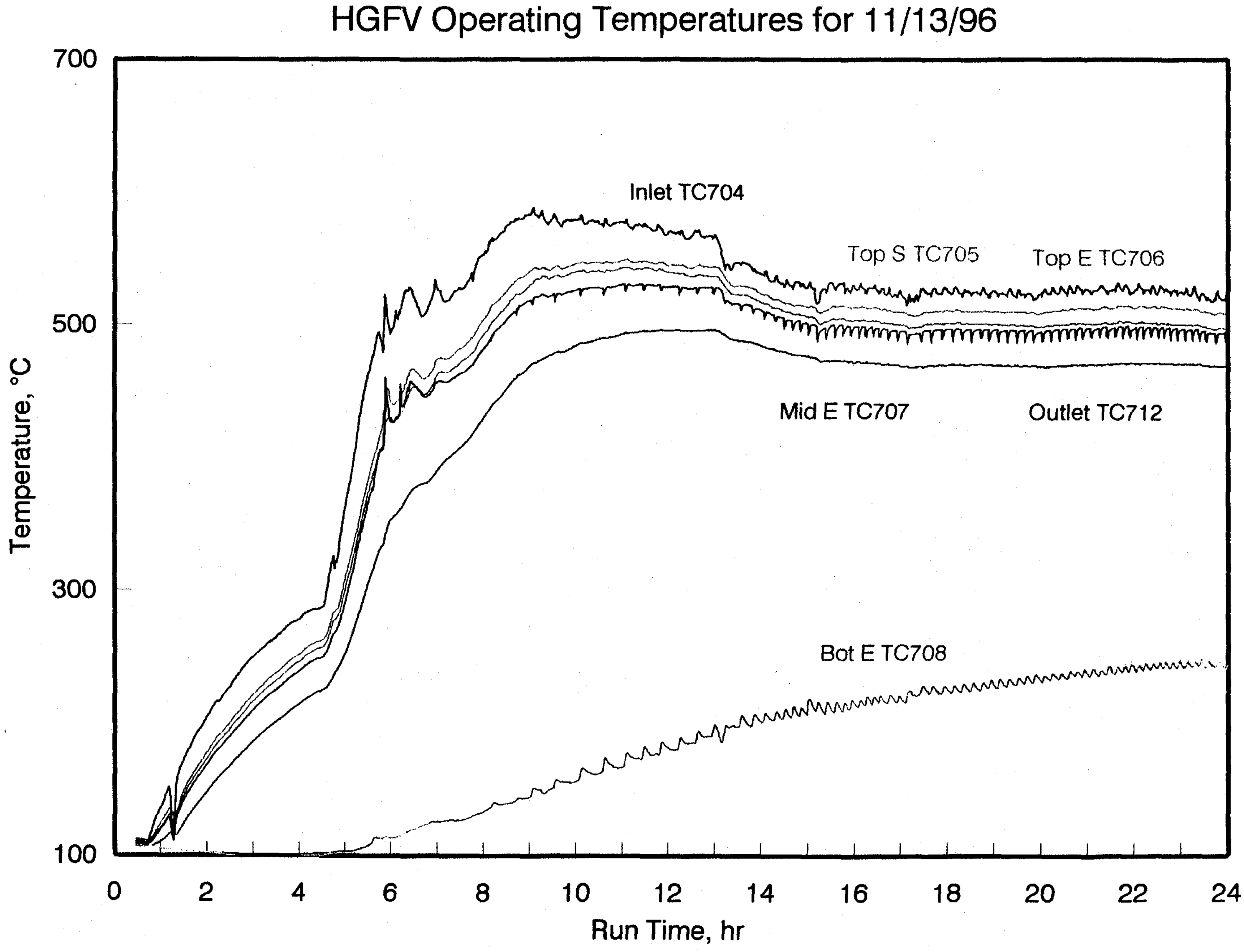

Figure 7. Hot-gas filter vessel temperature profile for 11/13/96.

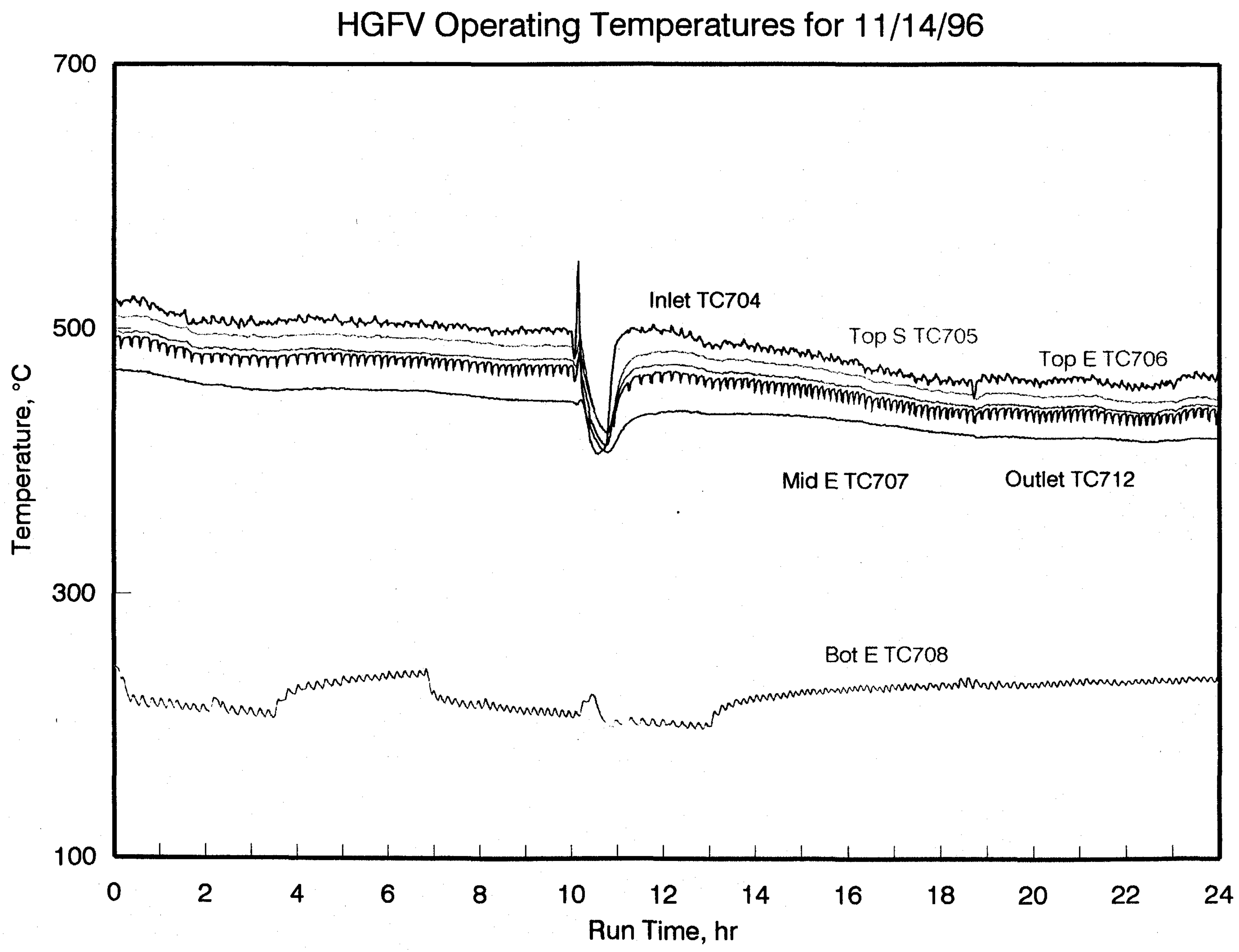

Figure 8. Hot-gas filter vessel temperature profile for 11/14/96.

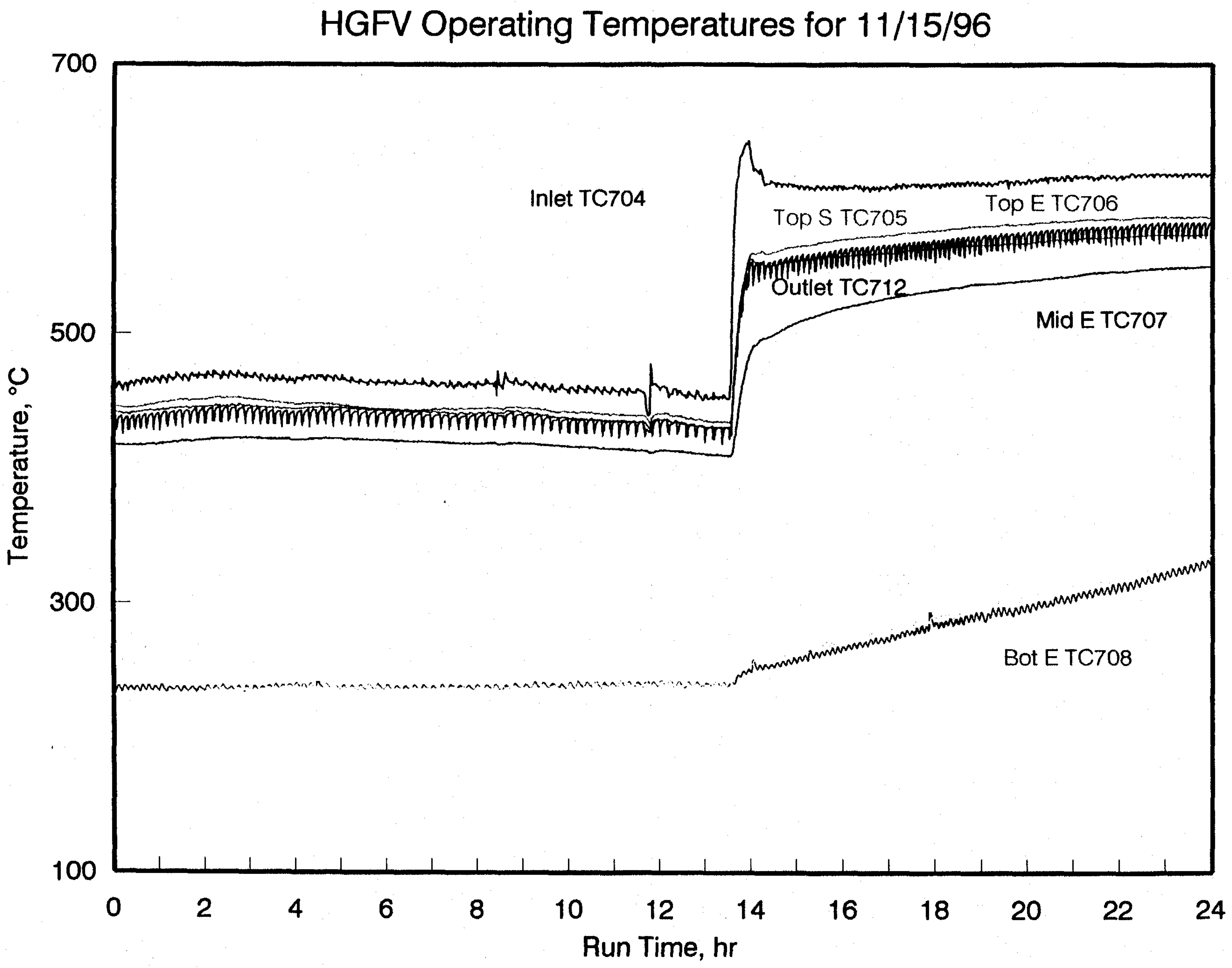

Figure 9. Hot-gas filter vessel temperature profile for 11/15/96.

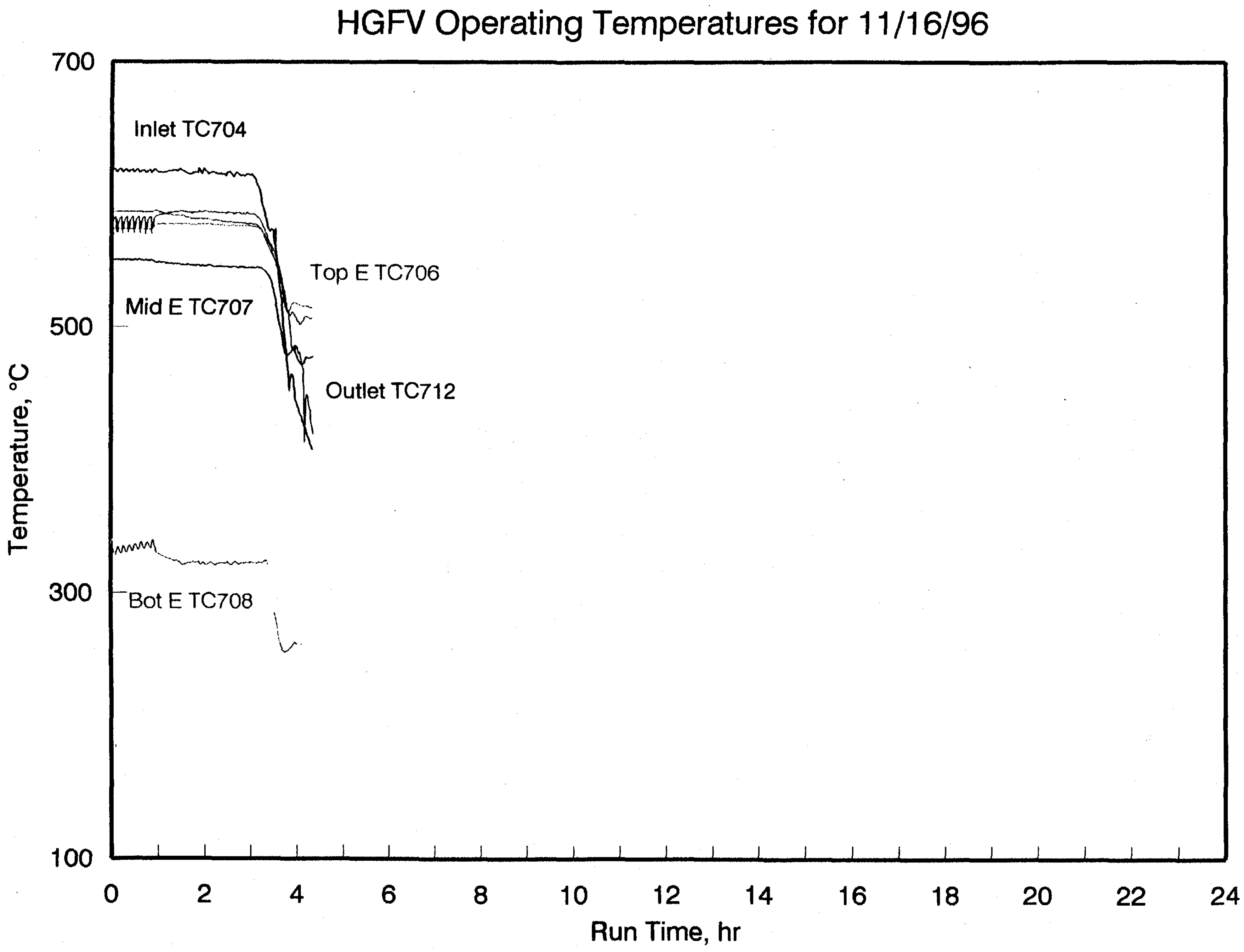

Figure 10. Hot-gas filter vessel temperature profile for 11/16/96.

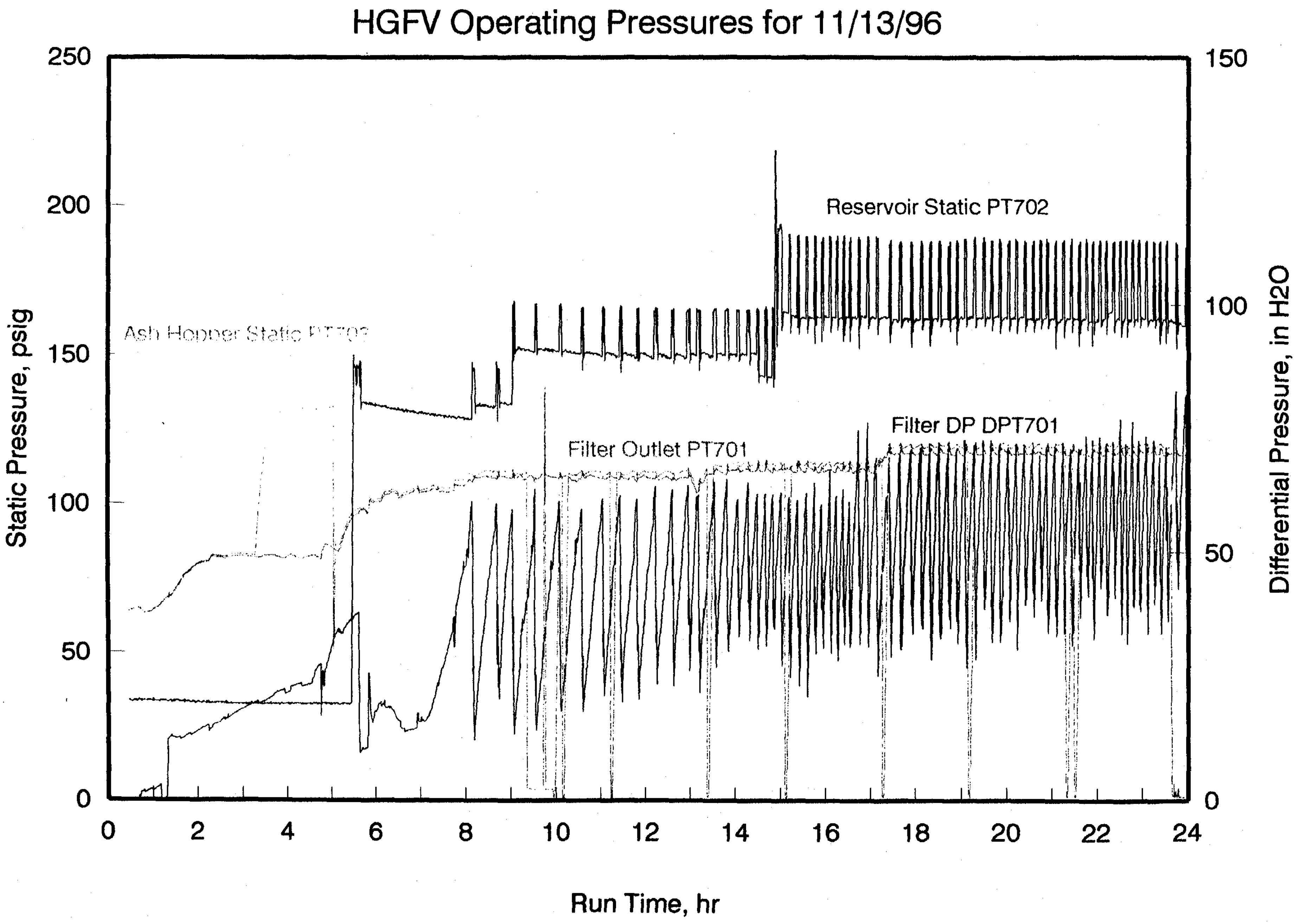

Figure 11. Hot-gas filter vessel pressure profile for 11/13/96.

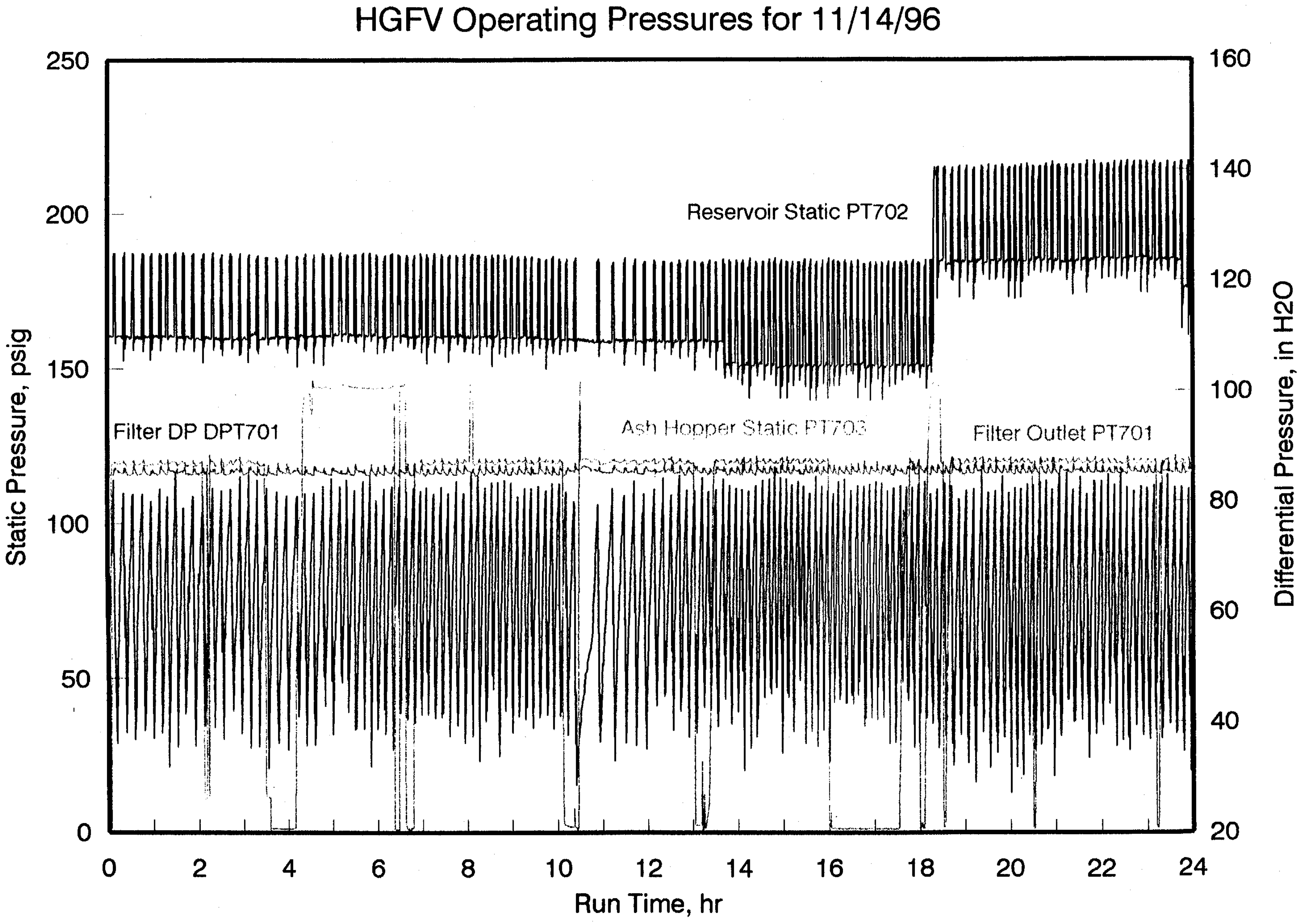

Figure 12. Hot-gas filter vessel pressure profile for 11/14/96.

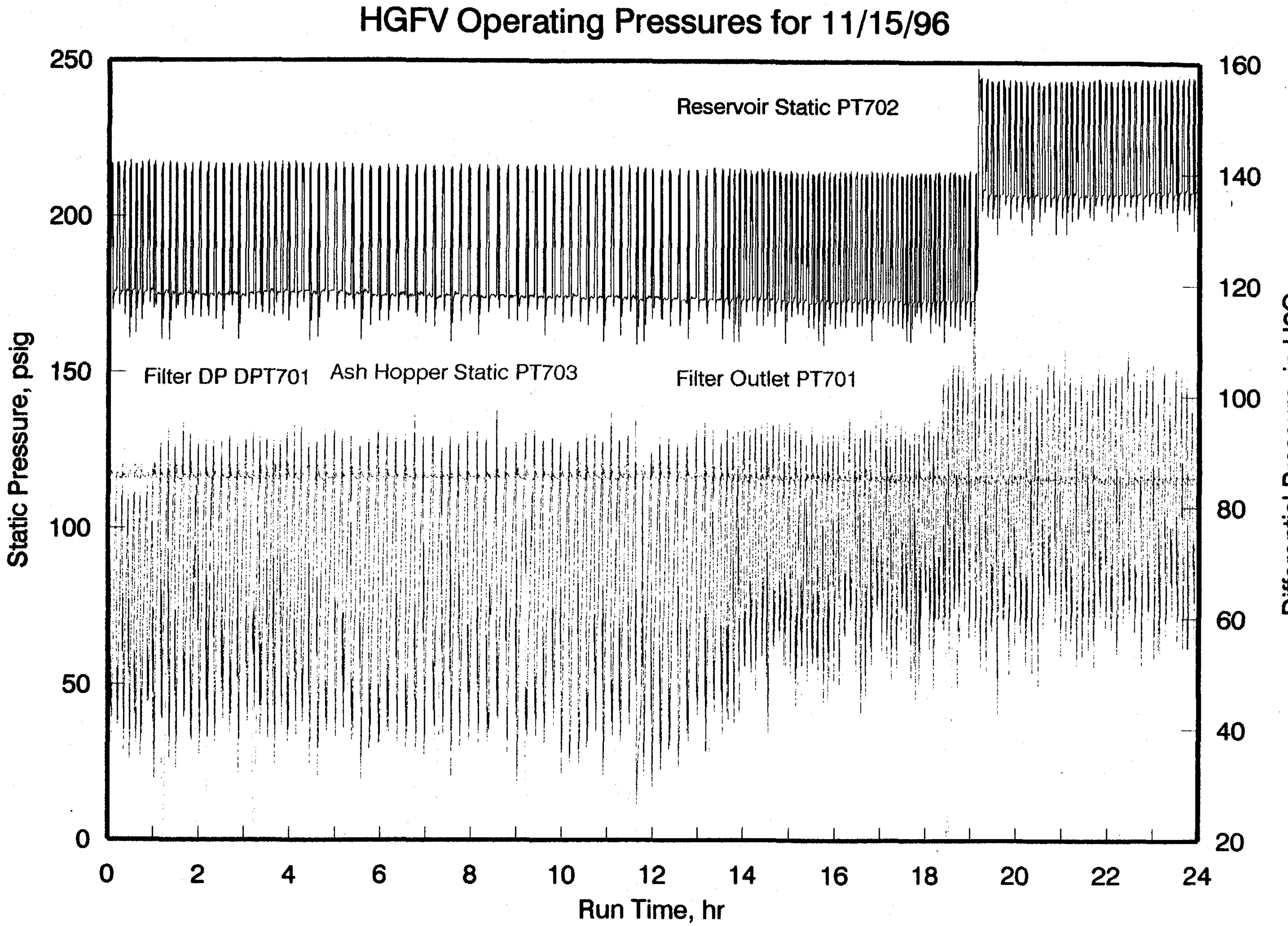

Figure 13. Hot-gas filter vessel pressure profile for 11/15/96.

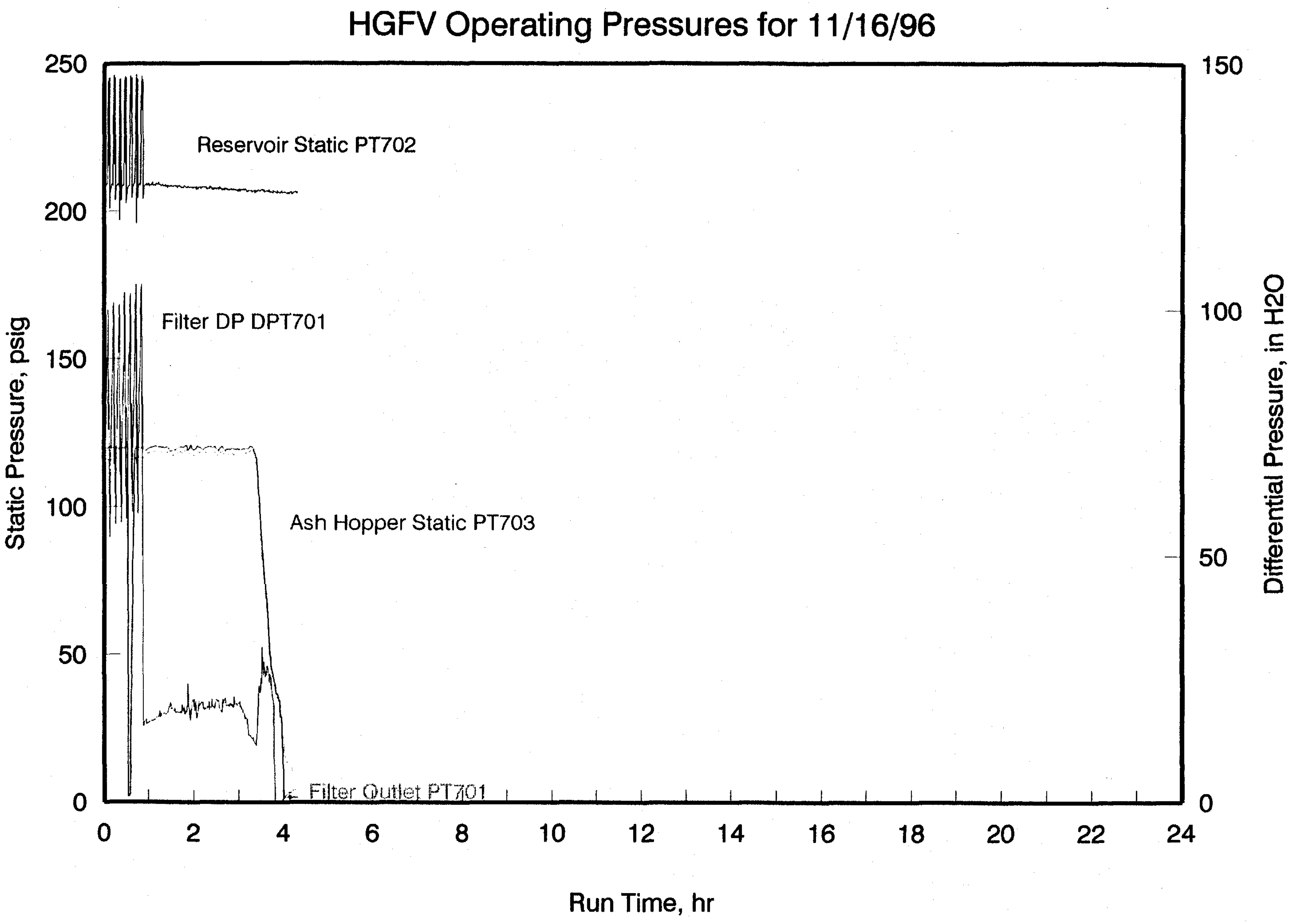

Figure 14. Hot-gas filter vessel pressure profile for 11/16/96.

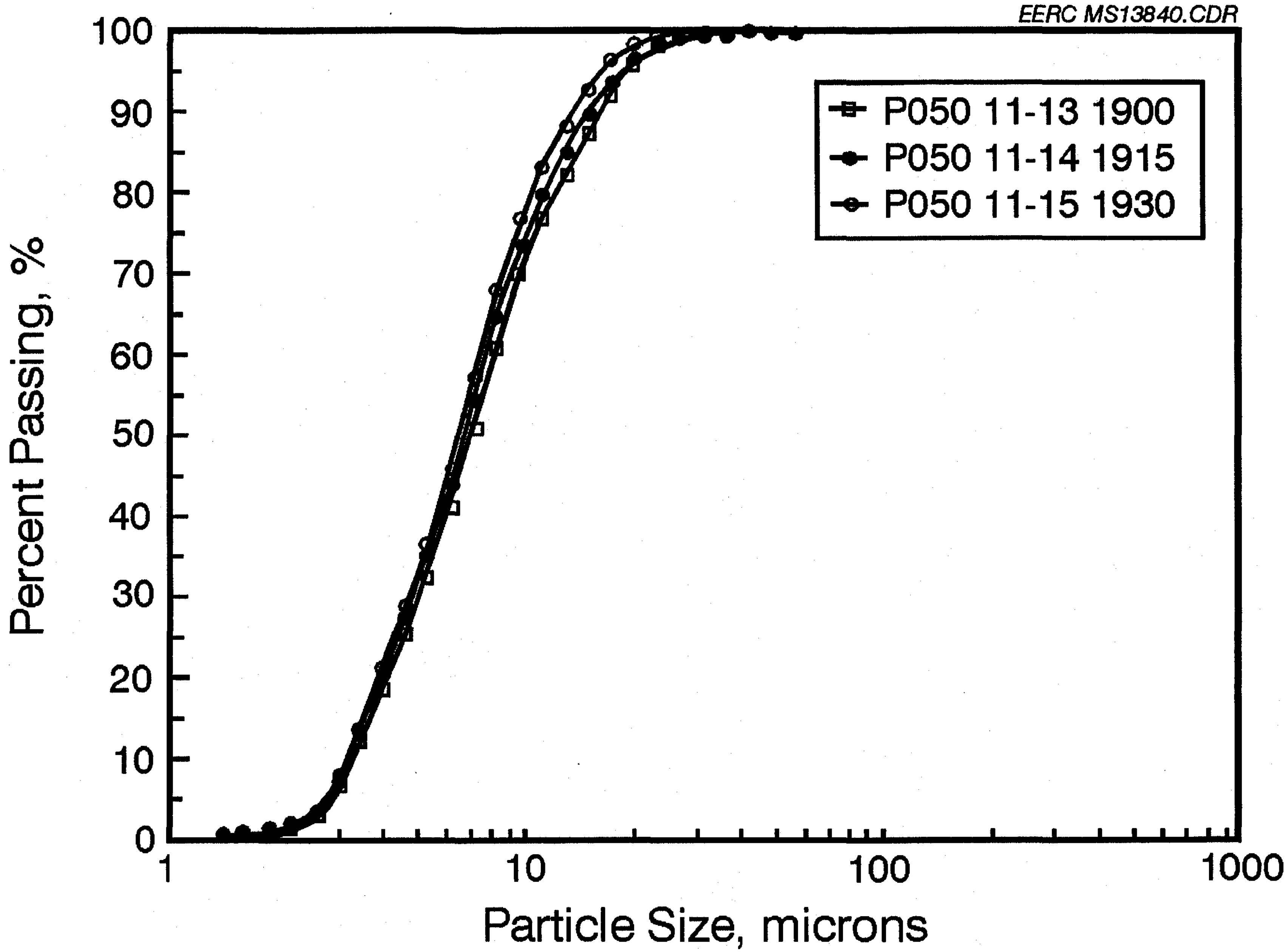

Figure 15. Particle-size distribution of filter ash for test P050.

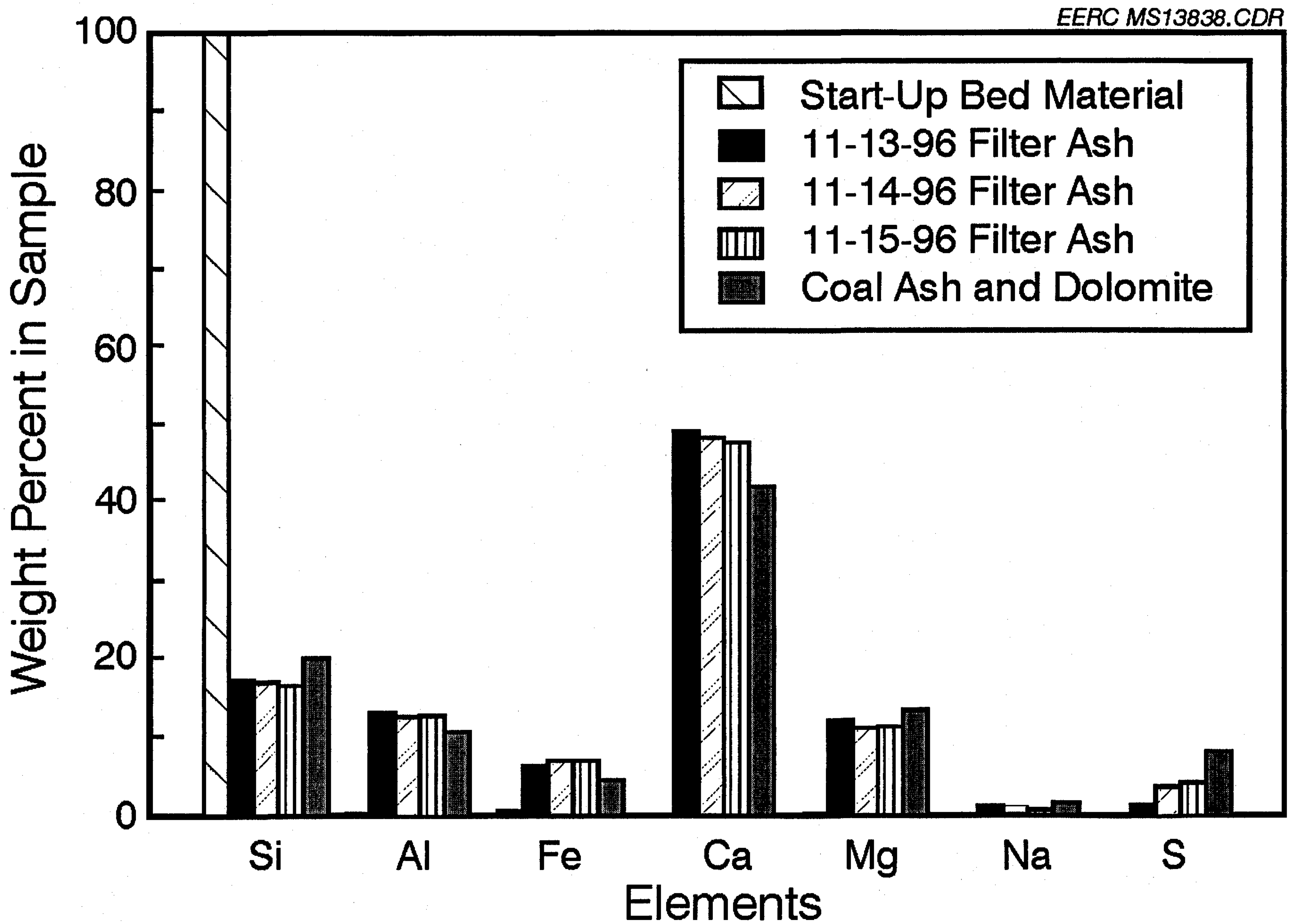

Figure 16. Chemical composition of filter ash for test P050.

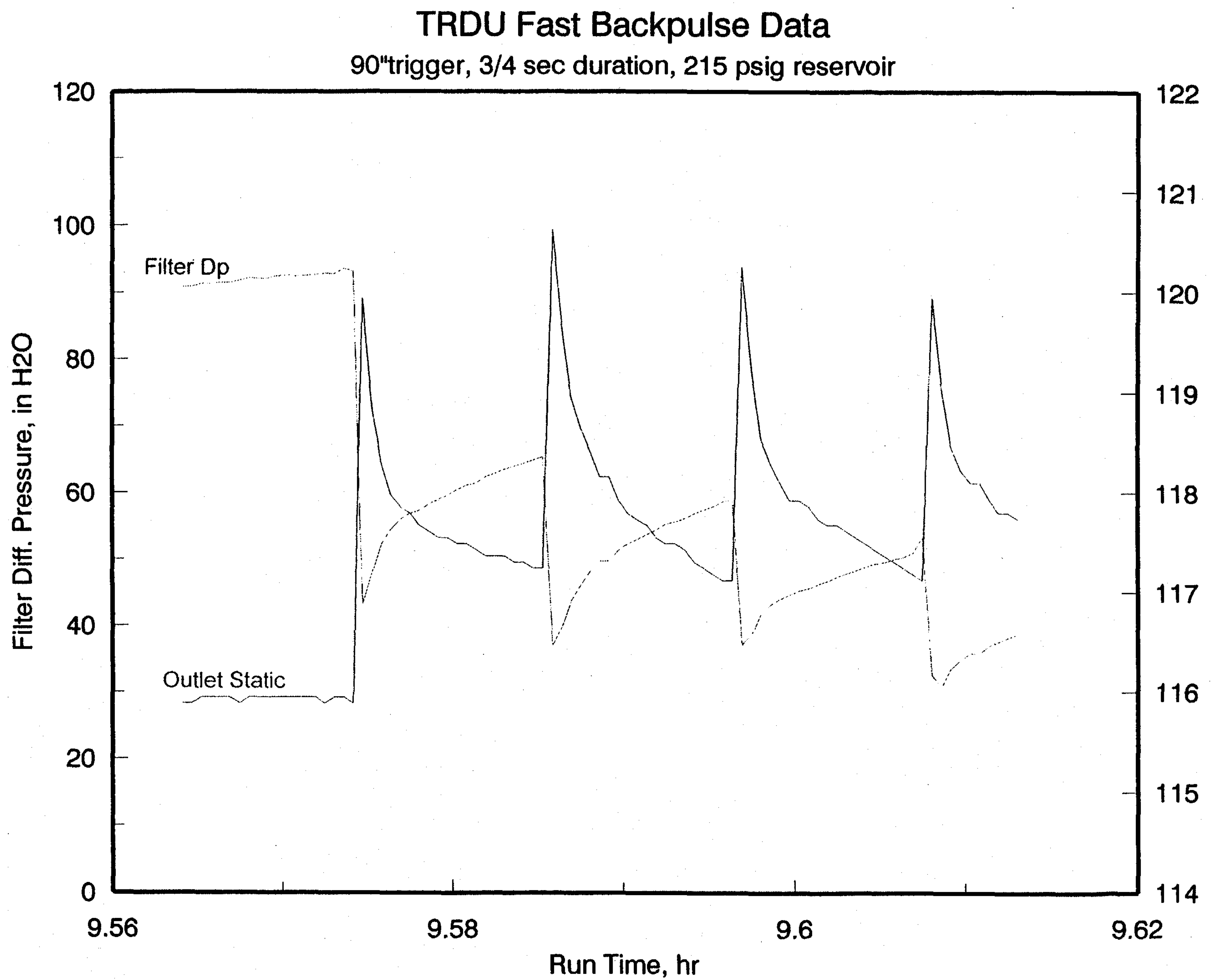

Figure 17. High-speed plots of filter vessel differential pressure and outlet static pressure for a backpulse from Test P050; baseline 90 H_2O trigger, 215 psig reservoir, and 3/4 sec pulse duration.

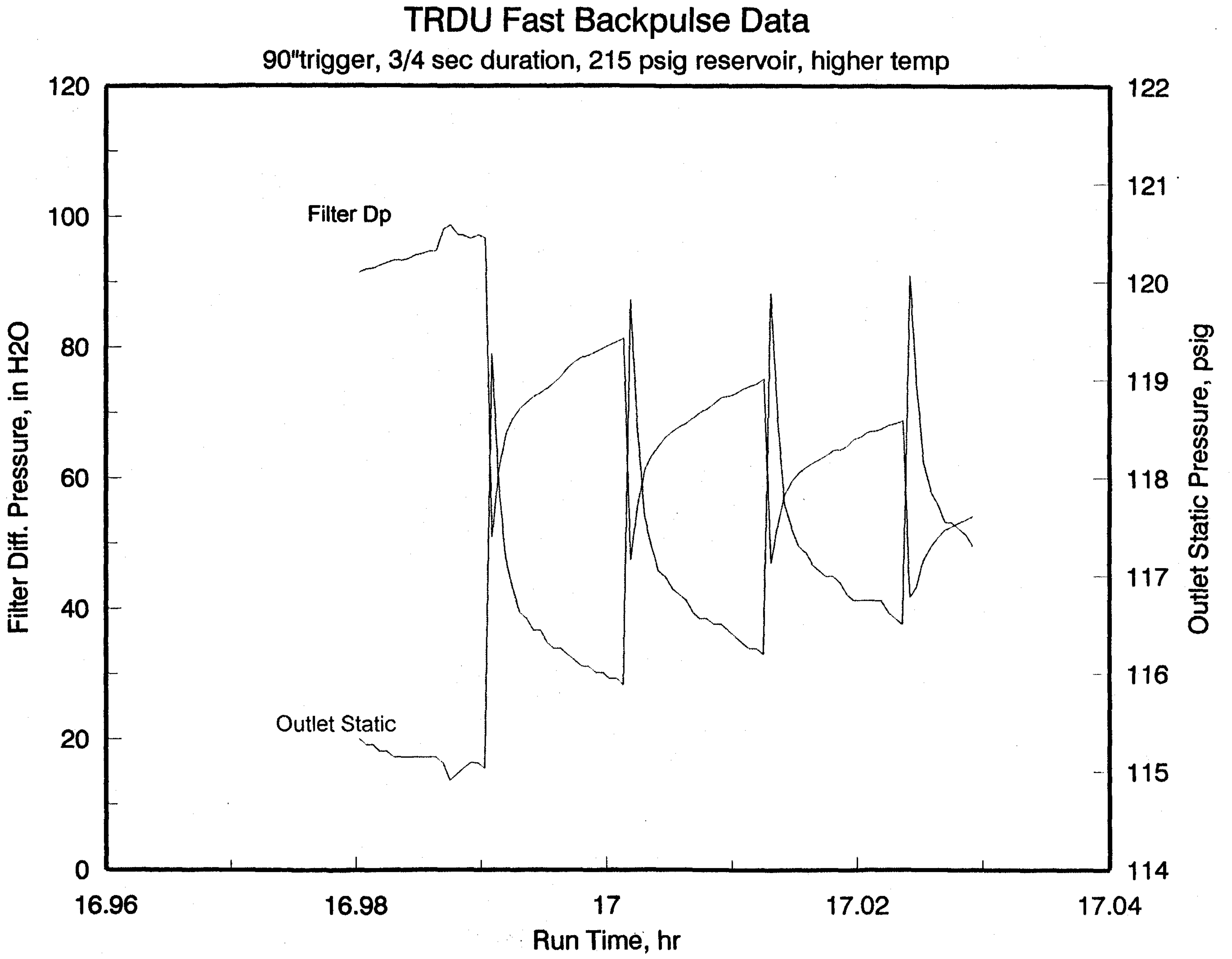

Figure 18. High-speed plots of filter vessel differential pressure and outlet static pressure for a backpulse from Test P050; same backpulse conditions but higher face velocity.

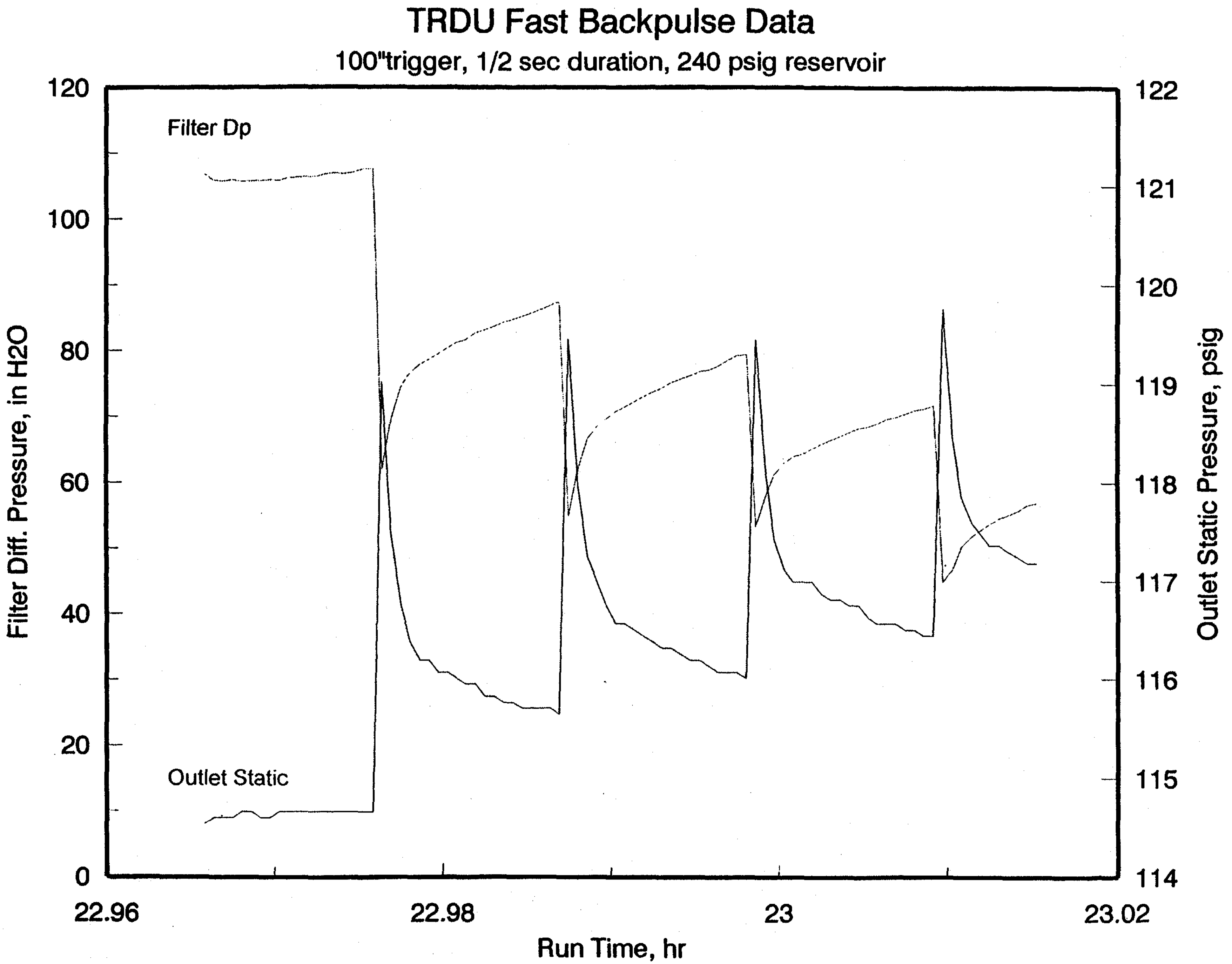

Figure 19. High-speed plots of filter vessel differential pressure and outlet static pressure for a backpulse from Test P050; baseline 100 H_2O trigger, 240 psig reservoir, and 1/2-sec pulse duration.

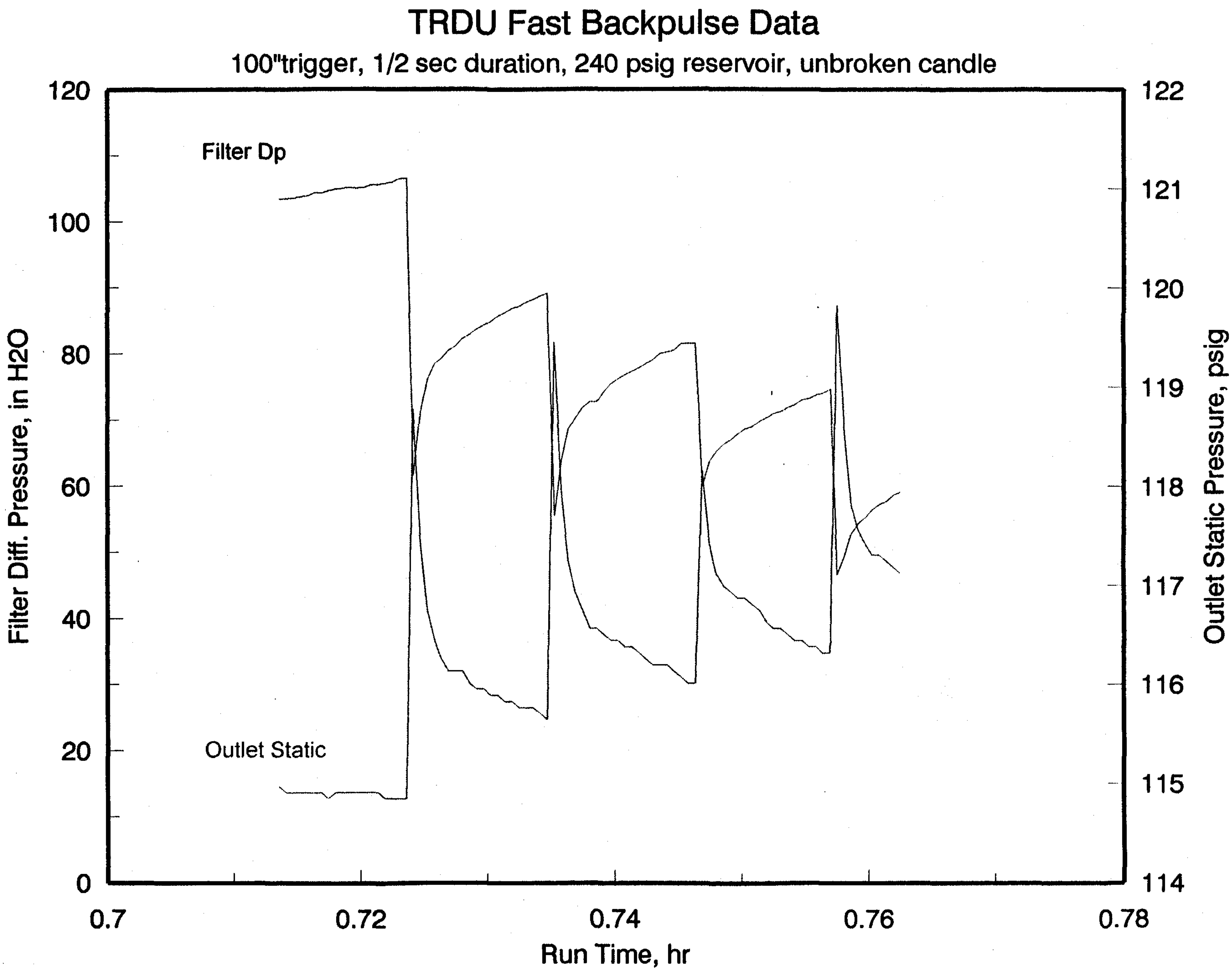

Figure 20. High-speed plots of filter vessel differential pressure and outlet static pressure for a backpulse from Test P050; same backpulse conditions but pulse before candle broke.

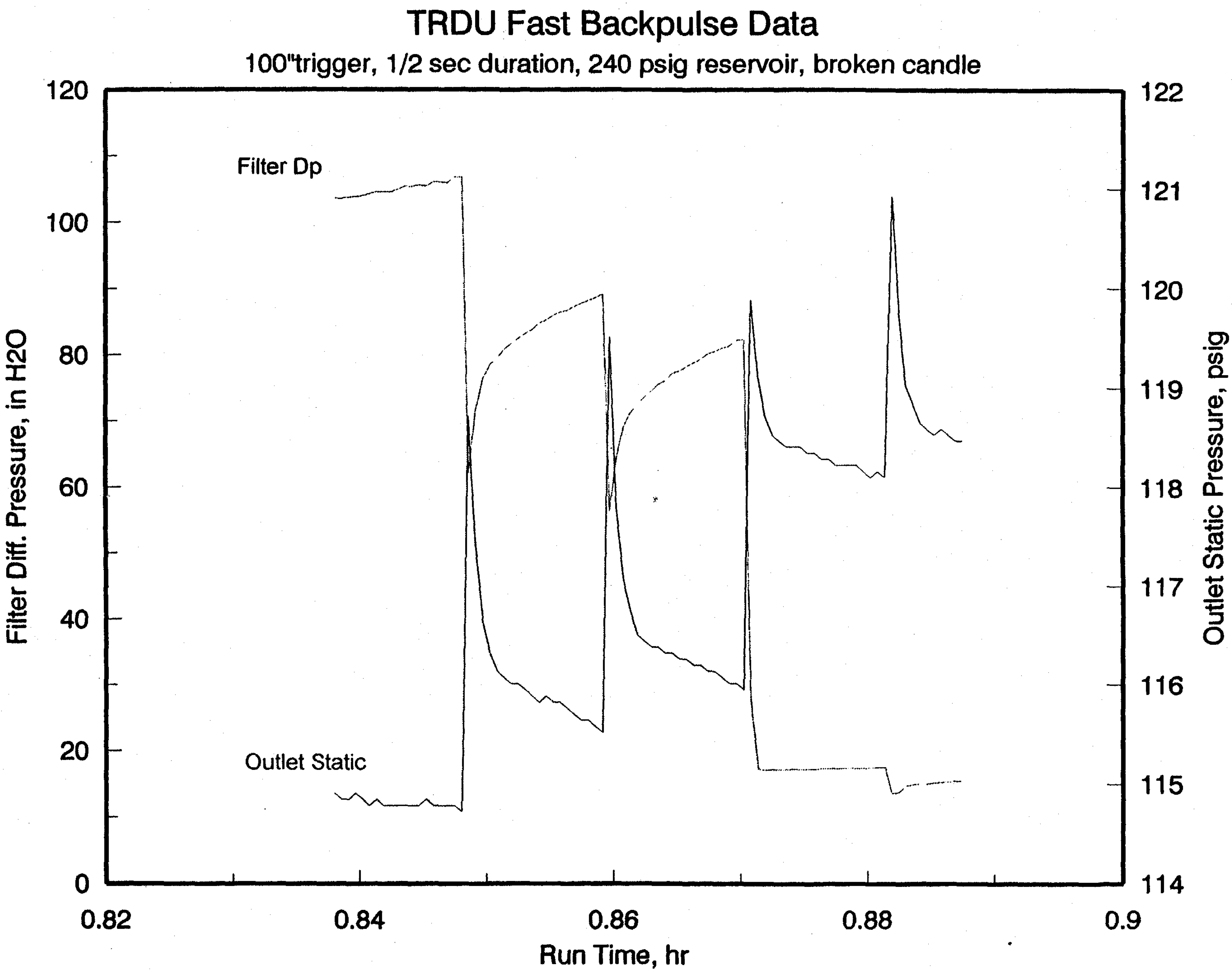

Figure 21. High-speed plots of filter vessel differential pressure and outlet static pressure for a backpulse from Test P050; same backpulse conditions but pulse which broke candle.

Figure 22. Photograph of HGFV candles after Test P050 including broken candle in foreground.

APPENDIX A

FILTER VESSEL AND BACKPULSE SYSTEM CHRONOLOGICAL SUMMARY

11/13/96

0300 Started coal feed

0700 Started coal gasification; backpulsed off combustion ash at a 60-in. H_2O trigger, 165 psig reservoir pressure and ¼-sec pulse duration

1426 Increased pulse duration to ½ sec

1501 Increased reservoir pressure to 185 psig

1635 Increased backpulse trigger to 70 in. H_2O

2236 Increased backpulse trigger to 80 in. H_2O

11/14/96

1045 Lost coal feed; feed hopper ran empty

1355 Increased pulse duration to ¾ sec

1818 Decreased pulse duration to ½ sec and increased reservoir pressure to 215 psig

2339 Increased pulse duration to ¾ sec

11/15/96

0059 Increased backpulse trigger to 90 in. H_2O

1332 Switched product gas heat exchanger to air cooling; step change in temperature and face velocity

1816 Increased backpulse trigger pressure to 100 in. H_2O

1908 Increased reservoir pressure to 240 psig

11/16/96

0053 Candle filter broke; backpulsing stopped

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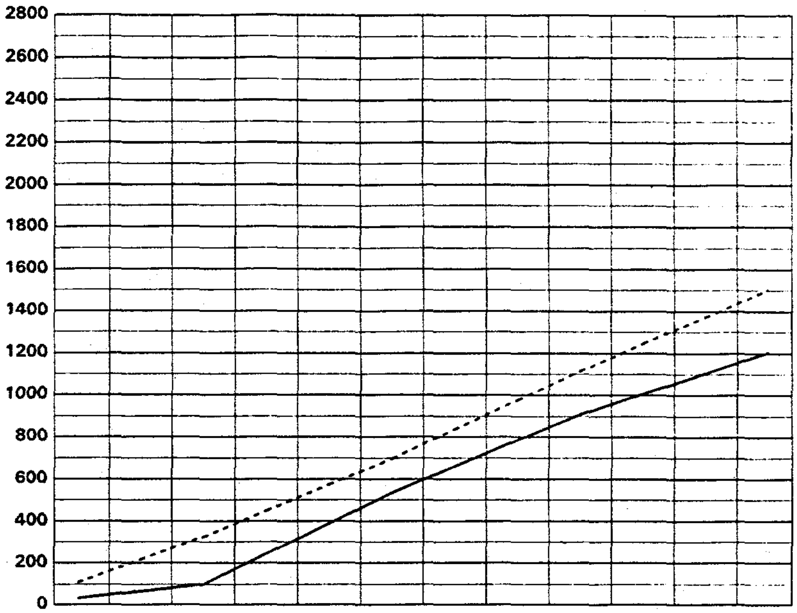
U.S. DEPARTMENT OF ENERGY
FEDERAL ASSISTANCE MANAGEMENT SUMMARY REPORT

FORM APPROVED
OMB NO. 1900 0127
Page 1 of 4

1. Program/Project Identification No. DE-FC21-93MC30097	2. Program/Project Title Task 3.0 Advanced Power Systems	3. Reporting Period 10-1-96 through 12-31-96
4. Name and Address	Energy & Environmental Research Center University of North Dakota PO Box 9018, Grand Forks, ND 58202-9018 (701) 777-5000	5. Program Start Date 01-12-93 6. Completion Date 12-31-97

7. FY	8. Months or Quarters	b. Dollar Scale	1st			2nd			3rd			4th		
95/96	Quarters		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC

9. Cost Status
a. Dollars Expressed In Thousands



10. Cost Chart

Fund Source		Quarter 1st	2nd	3rd	4th	Cum. to Date	Tot. Plan
DOE	P	324	374	417	387	1502	2657
	A	98	437	373	298	1206	
	P						
	A						
	P						
	A						
	P						
	A						
Total P		324	374	417	387	1502	2657
Total A		98	437	373	298	1206	
Variance		226	(63)	44	89	296	

P = Planned A = Actual

Total Planned Costs for Program/Project
$2657

c. Cumulative Accrued Costs

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Planned			324			698			1115			1502
Actual			98			535			908			1206
Variance			226			163			207			296

11. Major Milestone Status	Units Planned Units Complete
3.11 Fuel Quality Advisor	P
	C
3.12 Small Power Systems	P
	C
3.13 Hot-Gas Filter Testing	P
	C
3.14 Remote Power Gen. Alaska	P
	C
	P
	C
	P
	C
	P
	C
	P
	C
	P
	C

12. Remarks

13. Signature of Recipient and Date
1/31/97

14. Signature of DOE Reviewing Representative and Date

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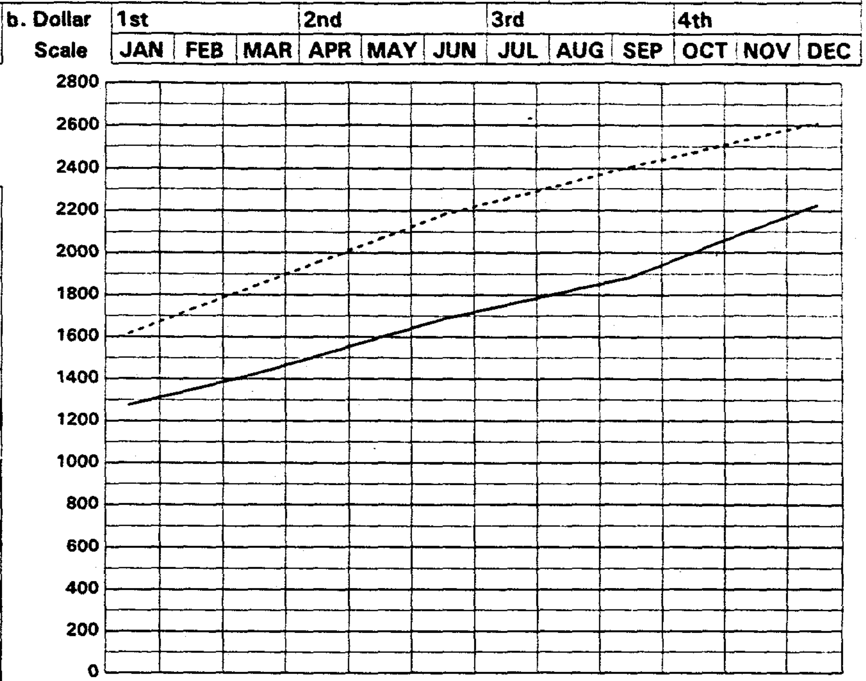
7. FY 96/97	8. Months or Quarters Quarters	

9. Cost Status a. Dollars Expressed In Thousands

b. Dollar Scale



10. Cost Chart

Fund Source		Quarter 1st	2nd	3rd	4th	Cum. to Date	Tot. Plan
DOE	P	341	334	229	206	2612	2657
	A	214	264	201	342	2227	
	P						
	A						
	P						
	A						
	P						
	A						
Total P		341	334	229	206	2612	2657
Total A		214	264	201	342	2227	
Variance		127	70	28	(136)	385	

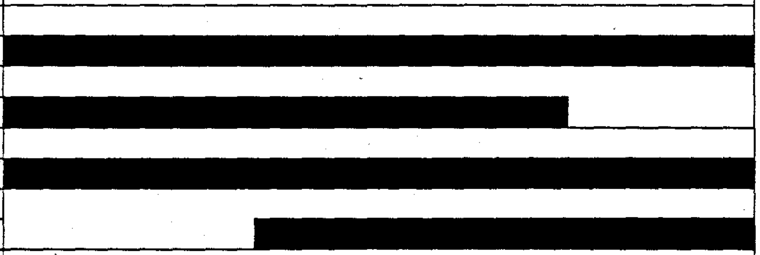
P= Planned A = Actual

Total Planned Costs for Program/Project
$2657

c. Cumulative Accrued Costs

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Planned			1843			2177			2406			2612
Actual			1420			1684			1885			2227
Variance			423			493			521			385

11. Major Milestone Status	Units Planned Units Complete
3.11 Fuel Quality Advisor	P
	C
3.12 Small Power Systems	P
	C
3.13 Hot-Gas Filter Testing	P
	C
3.14 Remote Power Gen. Alaska	P
	C
	P
	C
	P
	C
	P
	C
	P
	C
	P
	C



12. Remarks Please note the quarterly expenditures for the third quarter have been revised from $316 to $201(thousand). It appears the encumbrances were incorrectly included in quarter three.

13. Signature of Recipient and Date
1/31/97

14. Signature of DOE Reviewing Representative and Date

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7. FY 97/98	8. Months or Quarters Quarters	b. Dollar Scale	1st			2nd			3rd			4th			
			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	

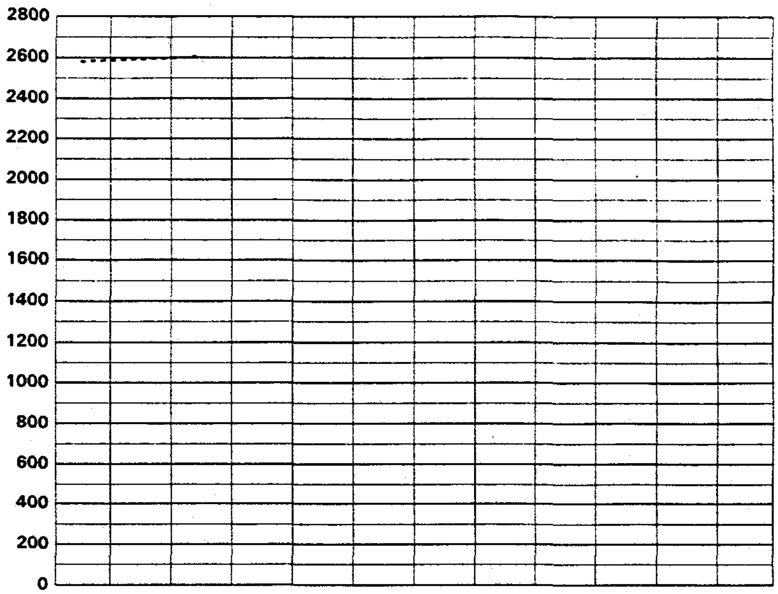
9. Cost Status a. Dollars Expressed In Thousands

10. Cost Chart

Fund Source		Quarter 1st	2nd	3rd	4th	Cum. to Date	Tot. Plan
DOE	P	45				2612	2657
	A					2227	
	P						
	A						
	P						
	A						
	P						
	A						
Total P		45	0	0	0	2612	2657
Total A		0	0	0	0	2227	
Variance		45	0	0	0	385	

P= Planned A = Actual

Total Planned Costs for Program/Project
$2657



c. Cumulative Accrued Costs

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Planned			2657			2657			2657			2657
Actual												
Variance												

11. Major Milestone Status	Units Planned Units Complete
3.11 Fuel Quality Advisor	P C
3.12 Small Power Systems	P C
3.13 Hot-Gas Filter Testing	P C
3.14 Remote Power Gen. Alaska	P C
	P C
	P C
	P C
	P C
	P C

12. Remarks

13. Signature of Recipient and Date
1/31/97

14. Signature of DOE Reviewing Representative and Date

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4. Name and Address	Energy & Environmental Research Center University of North Dakota PO Box 9018, Grand Forks, ND 58202-9018 (701) 777-5000	**5. Program Start Date** 01-12-93 **6. Completion Date** 12-31-97

Milestone ID. No.	Description	Planned Completion Date	Actual Completion Date	Comments
3.11	Fuel Quality Advisor	12-95		
a	Develop indices for ranking coal handleability	11-95	11-95	
b	Develop algorithms for incorporation into low-NOx ash formation model	9-95	7-96	
c	Develop algorithms for incorporation into the entrained flow gasification ash formation model	11-95	12-95	
d	Create a standardized and computerized shell and interface	7-95	7-96	
e	Incorporate ash formation, ash deposition, and coal handleability algorithms into Fuel Quality Advisor shell	12-95	7-96	
3.12	Small Power Systems	12-95		
1a	Identify best candidate sorbent for use in optimization studies	7-95	4-95	
1b	Determine optimal performance over operating range	12-95	--	Deleted
2a	Review the available data and select the best candidate cracking catalyst	4-95	9-95	Revised date 8-95
2b	Determine optimum operating conditions for the catalyst	12-95	--	Incorporate into 3c
3a	Select design(s) for further development	8-95	9-95	
3b	Identify barrier issues and develop demonstration and commercialization plan	12-95	9-95	
3c	Testing of barrier issues on pilot scale	12-95	12-95	Expanded scope
3.13	Hot-Gas Filter Testing			
a	TRDU upgrades	6-95	8-95	
b	Assembly and Installation of Filter Vessel	6-95	9-95	
c	200-HR FILTER TEST (shakedown)	9-95	12-95	Shorter test performed
d	Topical Report on First Filter Test	12-95	7-96	
e	Complete first 200-hr test	5-96	4-96	
f	Present Test Results to METC Representatives	7-96	7-96	
g	Complete Second 200-hr Test	11-96	11-96	
h	Present Test Results to METC Representatives	1-97		
3.14	Remote Power Gen. Alaska			
a1	Environmental Information Documentation	6-7-95	6-95	
a2	Regional Workshop	9-15-95	9-95	
a3	Site and Technology Selection	10-30-95	1-96	
a4	Status Report on McGrath AFBC Demonstration	6-96	6-96	
b1	Identify Environmental and Permitting Regulations	2-28-96		2-97
b2	Preliminary Engineering Design	5-31-96		3-97
	- Final Feasibility for McGrath Site	3-97		
	- Tok Site Preliminary Design	3-97		
c1	Evaluation of Technical Feasibility of Relocating Clean Coal Technologies to Alaska	12-31-95	9-96	*
c2	NEPA document preparation for CCT project in Alaska	2-97		

* Transfer of project approved