Instrumentation and Controls Division

THE BLEND DOWN MONITORING SYSTEM DEMONSTRATION AT THE PADIJCAH GASEOUS DIFFUSION PLANT

José March-Leuba, Danny Powell, James Sumner, Taner Uckan, and Robert Vines
Oak Ridge National Laboratory'

Donald Close, William Johnson, Jr., Phillip Kerr, and Calvin Moss
Los Alamos National Laboratory[2]

Paul D. Wright
U.S. Enrichment Corporation Paducah Gaseous Diffusion Plant

Edward Mastal and Janie Benton
U.S. Department of Energy

Presented at the
Institute of Nuclear Materials Management Meeting
July 25 - 29, 1999
Phoenix. Arizona

[1]Research sponsored by the U.S. Department of Energy and performed at Oak Ridge National Laboratory, managed by Lockheed Martin Energy Research Corp., for the U.S. Department of Energy under contract DE-AC05-96OR22464.
[2] The U.S. Department of Energy under contract W-7405-ENG-36

THE BLEND DOWN MONITORING SYSTEM DEMONSTRATION AT THE PADUCAH GASEOUS DIFFUSION PLANT

Jose March-Leuba, Danny Powell, James Sumner, Taner Uckan, and Robert Vines
Oak Ridge National Laboratory'

Donald Close, William Johnson, Jr., Phillip Kerr, and Calvin Moss
Los Alamos

Implementation of the Paducah Demonstration

To properly simulate operation of the equipment in a Russian Federation blending facility, gaseous UF_6 at a known assay and flow rate was required. An assay of I .5% was selected for the demonstration because of its availability. In addition, performing the demonstration with 1.5% UF_6 would serve as a worst case for demonstrating the capabilities of the BDMS equipment. Rather than set up a dedicated facility to demonstrate the FMFM and EM equipment, it was decided to use an existing facility where UF_6 was available for performing the demonstration. There are two such facilities in the United States: PGDP located in Paducah, Kentucky, and the Portsmouth Gaseous Diffusion Plant located in Piketon, Ohio. Both facilities are operated by the United States Enrichment Corporation (USEC). For logistical reasons, it was decided to perform the demonstration at Paducah. Figure 1 shows the demonstration stand installed at PGDP with the assembled and operational BDMS equipment.

Results of the Paducah Demonstration

The primary emphasis of the Paducah demonstration was to demonstrate the operation of the BDMS equipment at operating conditions similar to those expected to be encountered in a typical HEU down-blending facility. Although it was not possible to demonstrate the BDMS equipment operation at all of the assays, pressures, or flow rates, corresponding operating conditions were developed to simulate the operation of the equipment under these conditions by varying the UF_6 gas pressure. This resulted in an "effective" ^{235}U density that simulated different assays or pressures. In addition to demonstrating equipment operation at these representative operating conditions, the equipment was operated under a variety of pressures and flow rates to fully characterize its operational abilities at possible off-normal conditions.

Table 1 shows a typical range of expected operating conditions compared with the operating parameters during the Paducah demonstration.

Table 1. Typical expected operating conditions versus the Paducah demonstration operating conditions

	Range of operating conditions			Paducah Demonstration
	HEU	Blend stock LEU	Product LEU	
Velocity (m/s)	-0.1	~2-3	~2-3	0.03–2.8
^{235}U mass flow (g/s)	~0.5	~0.2	~0.7	0.1-1
^{235}U density (g/m)	-5	-0.1	~0.3	0.1–0.45
Enrichment (%)	~90	~1.5	~4	1.1-1.55
Pressure (psia)	-0.8	~0.8	~0.8	~1.5–4.5

As seen in the table, the gas velocity and mass flow conditions measured in Paducah cover the expected range of the typical operating conditions. The measured ^{235}U densities cover the expected range of operation in both the blend stock and P-LEU lines, which represent more difficult measurements than the HEU line. Due to facility constraints, the lowest pressure achieved during the Paducah demonstration was approximately 1.5 psia, but the pressure effects are well understood and do not compromise the results of the demonstration.

A. BDMS Enrichment Monitor and Results

The EM system is designed to measure the assay of gaseous UF_6 in process pipes. The assay is defined as the ratio of the amount of ^{235}U to the total amount of uranium present. Two measurements are required to determine the enrichment. One measurement is needed to determine the amount of ^{235}U in the gas, and the second measurement is needed to determine the total amount of uranium in the gas.

The first measurement is a passive measurement of the intensity of the 186-keV g-a ray from the alpha decay of ^{235}U to ^{31}Th, and hence the amount of ^{235}U. It is expected in general that in addition to the UF_6 gas in the process pipe there will be uranium deposits on the inside surface of the process pipe. A measurement with the process pipe empty of process gas is required to determine the amount of the deposit. This becomes one type of background correction in the analysis to determine the amount of ^{235}U in the gas. For the new monel pipe in the demonstration at Paducah, this background correction was expected to be zero initially. Another reason to measure the process pipe empty of process gas is to determine all room background corrections needed for the 186-keV gamma-ray signal. The amount of ^{235}U in the pipe is dependent on the enrichment and the process gas pressure.

The total amount of uranium in the gas is determined by the attenuation of the 122-keV g-a ray from a ^{57}Co transmission source through the process pipe, any deposit, and the gas. Measurement of the source strength with the process pipe empty of process gas is required to determine the attenuation by the process pipe and deposits. This datum is necessary to analyze the measurements with gaseous UF_6 in the process pipe to determine the total amount of uranium in the UF_6. The transmission measurement through gaseous UF_6 is dependent on the pressure of the process gas. The combination of these two measurements gives the enrichment, or percentage, of ^{235}U in the process gas independent of the process gas pressure. The passive measurement of the 186-keV gamma ray and the transmission measurement through the process gas are made simultaneously.

Physical characteristics of the facility and the measurement system will affect the background in both the 122-keV and 186-keV regions of the gamma-ray spectrum. Spectra are taken with the EM installed and under different conditions: with ^{57}Co and ^{252}Cf sources in and out of the BDMS instruments and with the UF_6 process gas in and out of the process pipe. These spectra are used to quantify these effects and to characterize the operation of the EM under facility-specific conditions.

The BDMS EM accurately monitored the ^{235}U enrichment during the course of the Paducah demonstration. Figures 2 and 3 show plots of the EM enrichment measurements for runs that were a minimum of 2-hours. Actual assays are also plotted in these figures. The initial assays were approximately 1.55% and gradually decreased beginning on June 23 until the assay reached approximately 1.1% on June 26. The large majority of data points lie within one statistical standard deviation of the plant assay values. Enrichment values are not shown for the periods from May 4 to May 12 and from June 4 to June 19, when the pipe was purged of UF_6 gas. The interval between May 23 and June 4 is also absent of data because of a minor EM software problem. The problem was caused by a typographical error in the config.sys tile. The system accumulated data over the entire period, but the collected data were not written to a file at the specified intervals. The error was corrected on June 4.

As part of the demonstration, a range of gas pressures from 1.5 psia (approximately 80 Torr) to 4.5 psia (approximately 230 Torr) was presented to the BDMS. Figure 4 shows the plot of the EM measurements of the ^{235}U enrichment along with the pressure (which is directly correlated with the UF_6 density). Figure 4 shows that the EM results are insensitive to the gas pressure.

Figure 5 shows some of the information that is routinely available to U.S. monitoring personnel as output from **the HLX Maintenance** program. Figure 5 was generated using **HLX Maintenance** with data from the Paducah demonstration and is a plot of the average daily enrichment values for the period from April 19 to July 19.

Several items concerning the stability of the calibration were addressed during the demonstration. One important point was the possibility of uranium deposit buildup on the inner surface of the pipe. Deposit buildup would be indicated by a positive deviation of the measured 186-keV gamma-ray count rate from the predicted count rate as well as deviations between the EM measurements (EM measurements would indicate too high an enrichment) of the enrichment and the plant assays. Any deviation would be most apparent during periods in which the pipe was purged of UF_6. At the beginning of the demonstration, before gas was delivered to the pipe, the 186-keV gamma-ray count rate was 0.47 ± 0.6 c/s. During the periods when the pipe was purged of UF_6 (May 4 to May 12, June 4 to June 19, and July 24 to July 27), average 186-keV gamma-ray count rates were 0.49 ± 0.06, 0.59 ± 0.06, and 0.52 ± 0.06 c/s, respectively. It is therefore concluded that no significant uranium deposition occurred.

Another concern was the possibility of interference with the 122-keV and 186-keV photopeaks by the ^{252}Cf sources. Analysis of spectra taken with and without the ^{252}Cf sources present showed that the sources contributed a flat, featureless continuum in the energy region from 94 to 209 keV. This region spans the limits of the region-of-interest and background regions used to extract the 122-keV and 186-keV photopeak areas. Therefore, no significant interference from the ^{252}Cf sources was observed for the conditions encountered during the demonstration.

Throughout the demonstration, pipe temperature was maintained at an elevated level with heat tape. Pipe temperature can influence the gas temperature (and hence the gas density) and also the pipe-mounted instruments, which are in thermal contact with the pipe. At the end of the demonstration, the pipe temperature was manipulated by turning portions of the heat tape on and off to observe any effects on the EM measurements. A number of different source-in/source-out, gas-on/gas-off, and heat-tape-on/heat-tape-off measurements were made to discover possible temperature effects. The EM measurements were not affected by the temperature of the pipe.

The EM closely tracked facility-provided assays, including the period in which a reduction in the UF_6 enrichment occurred. The behavior of the 122-keV and 186-keV gamma-ray count rates, from which the EM calculates the enrichment, are well understood. The EM results also tracked the status of the pipe well in the periods when no gas was in the pipe: the 186-keV gamma-ray count rates were equal to previously determined background rates, and the 122-keV gamma-ray count rates were as expected for no attenuation by UF_6 gas. The flow rate and pressure of UF_6 were varied throughout the demonstration to map the operating envelope of the BDMS equipment. The EM equipment was demonstrated to be capable of measuring the enrichment of UF_6 independently of effects caused by variations in flow rate or pressure of the UF_6 gas.

B. BDMS Fissile Mass Flow Monitor and Results

The BDMS FMFM has two functions: (1) measure the mass flow rate of fissile material in a process pipe, and (2) trace the flow of the fissile material from the HEU process leg to the

P-LEU process leg of a blending tee. To achieve these functions, the FMFM induces fissions in the gas stream and measures the delayed gamma rays emitted by fission fragments at a downstream detector. The induced fissions are modulated by a neutron-absorbing shutter to create a time signature that is detected by the downstream detectors. The FMFM determines the fissile mass flow rate (measured in grams per second) by multiplying the measured flow velocity (measured in meters per second) by the measured fissile concentration (measured in fissile grams per meter of pipe). The flow velocity of the fissile material is obtained from a time-delay measurement and the distance between the source and the detector. The fissile concentration is derived from the number of detector counts that are correlated with the shutter motion. Fissile traceability is accomplished by detecting the presence of time-modulated fission fragments in the P-LEU process gas at a detector located downstream of the blending tee.

The basic concept for the FMFM measurement technique can be described by the following steps. (1) Fast neutrons from a ^{252}Cf source are moderated in a polyethylene block and induce fissions inside the process stream. (2) The resulting fission fragments are slowed down by the gas, and some are carried by the stream. (3) A downstream detector measures delayed gamma rays emitted by the fission fragments. (4) By modulating the source with a neutron-absorbing shutter, a time-dependent signature is superimposed in the fissile stream, and a time-delay measurement is performed by detecting the signature downstream. (5) The tissile concentration is obtained from the measured detector response and a calculated calibration that is confirmed by measurements. (6) The fissile mass flow rate is determined by multiplying the average tissile velocity, inferred from the time delay, and the tissile concentration of step (5).

This measurement methodology is insensitive to buildup on pipe walls, and it can be applied to any flow stream that can produce particles that emit delayed radiation that can be detected downstream. Delayed gamma rays were chosen for this application because of the significantly larger (by a factor of approximately 400) yield per fission than delayed neutrons.

Figure 6 shows a typical result from the Paducah demonstration measurements for a condition with a gas velocity of approximately 0.5 m/s and a source-detector separation of approximately 3-m. As seen in this figure, the neutron-absorber shutter opens at time zero, resulting in an instantaneous response at the detector location. This response is caused by a change in gamma-ray background induced by the change of neutron flux in the moderator. A fission fragment pulse is clearly observable with a time delay of approximately 6-s (equal to 3-m separation divided by 0.5-m/s velocity). The FMFM averages a large number of shutter motions to reduce the uncertainty of the measurement and then processes the data to identify a time delay and a pulse amplitude. The gas velocity is inferred from the time delay, and the ^{235}U concentration is related to the pulse amplitude. The fissile mass-flow rate is calculated by multiplying the gas velocity by the tissile concentration.

As shown in Figure 7, the BDMS FMFM equipment was operated successfully within an operating envelope bounded by pressures ranging from 1.5 to 4.5 psia, gas velocities ranging from 0.03 m/s to 2.8 m/s, and UF_6 mass flow rates ranging from 0 to 1 g/s. These conditions include both laminar and turbulent flow regimes, and the operation of the FMFM was successfully demonstrated under both regimes.

The FMFM was also evaluated for its ability to accurately detect a temporary loss in flow and repeatability during the subsequent flow restart. Figure 8 shows the resulting output from the

FMFM during one of these demonstrations. As can be seen from the figure, the FMFM proved capable of properly monitoring transients in the flow of UF_6 through the test stand.

A key characteristic of the FMFM is the ability to introduce a low-frequency time modulation in the quantity of fission fragments created in the HEU line. By detecting this time modulation in the P-LEU line, the FMFM system is capable of tracing HEU-line fission fragments through the blending point. This feature significantly increases confidence in monitoring the blending process because it allows for the tracing of HEU gas to the product line. This feature was successfully demonstrated at Paducah, and a typical result is shown in Figure 9. The example shown in Figure 9 corresponds to a situation in which gas flowing through the pipe at the 20-min-long low-frequency modulation is detected with high confidence (100%) in the downstream detectors. This traceability gives U.S. Monitors significant confidence that the HEU is indeed being blended into P-LEU.

Conclusions

The demonstration of the BDMS of LANL EM and ORNL FMFM equipment at the Paducah Gaseous Diffusion Plant was an unqualified success. In addition to successfully demonstrating the operation of the BDMS equipment, the demonstration provided the opportunity for a Russian delegation to witness the demonstration as well as providing an extremely valuable shakedown test of the equipment operation. Recently, the BDMS was successfully installed and implemented at the Ural Electrochemical Integrated Plant at Novouralsk, Russia, where it has been operational since February 2, 1999, and is performing as expected.

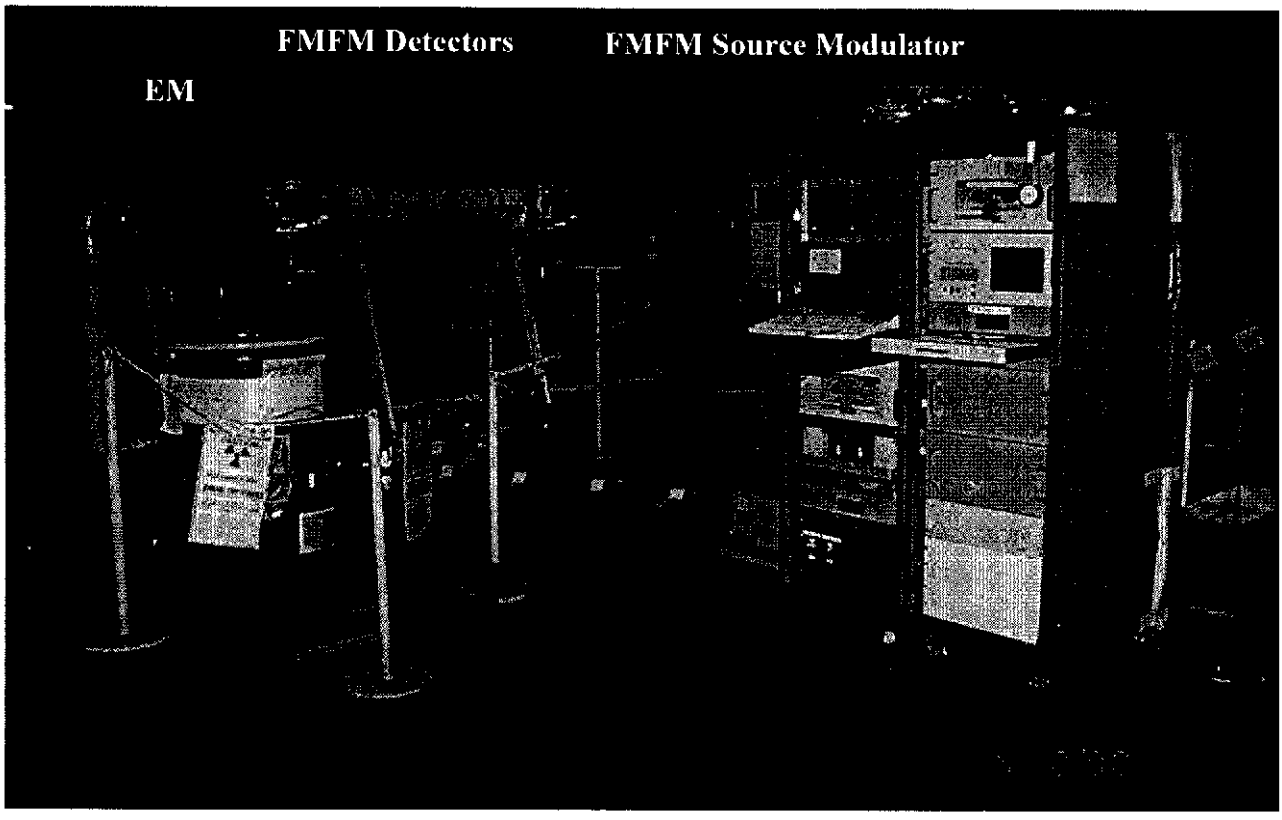


Fig. 1. Demonstration stand installed in Building C-310 at Paducah with assembled and operational BDMS equipment of EM and FMFM.

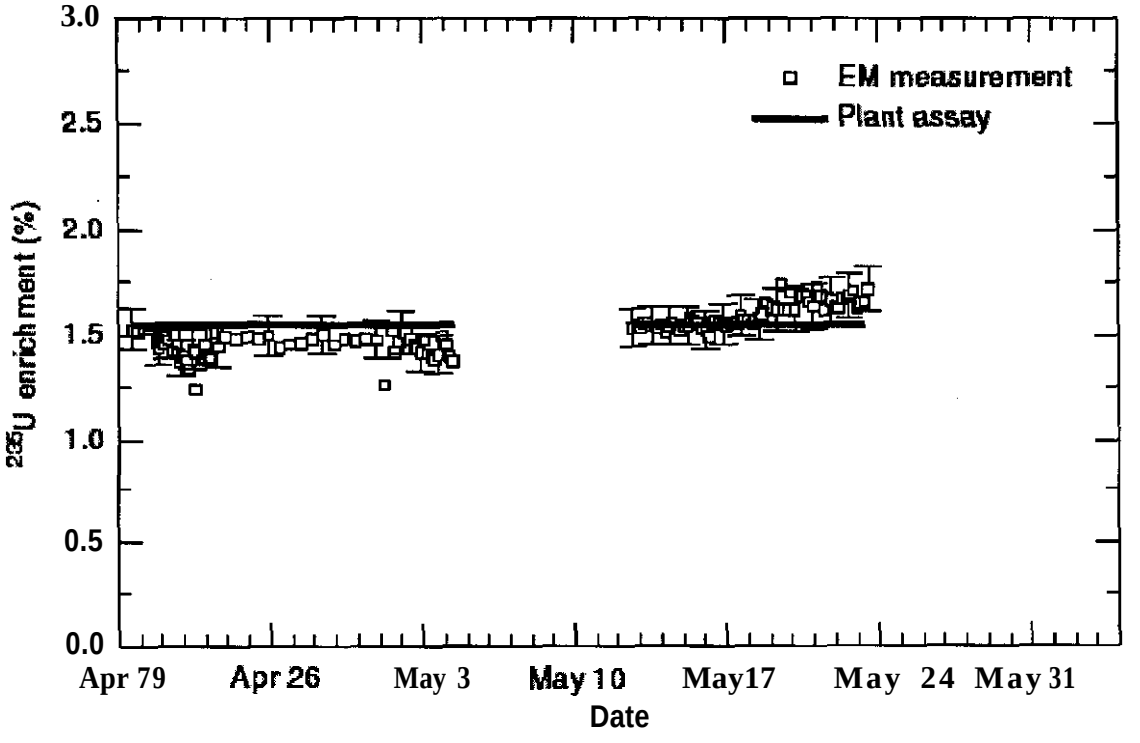
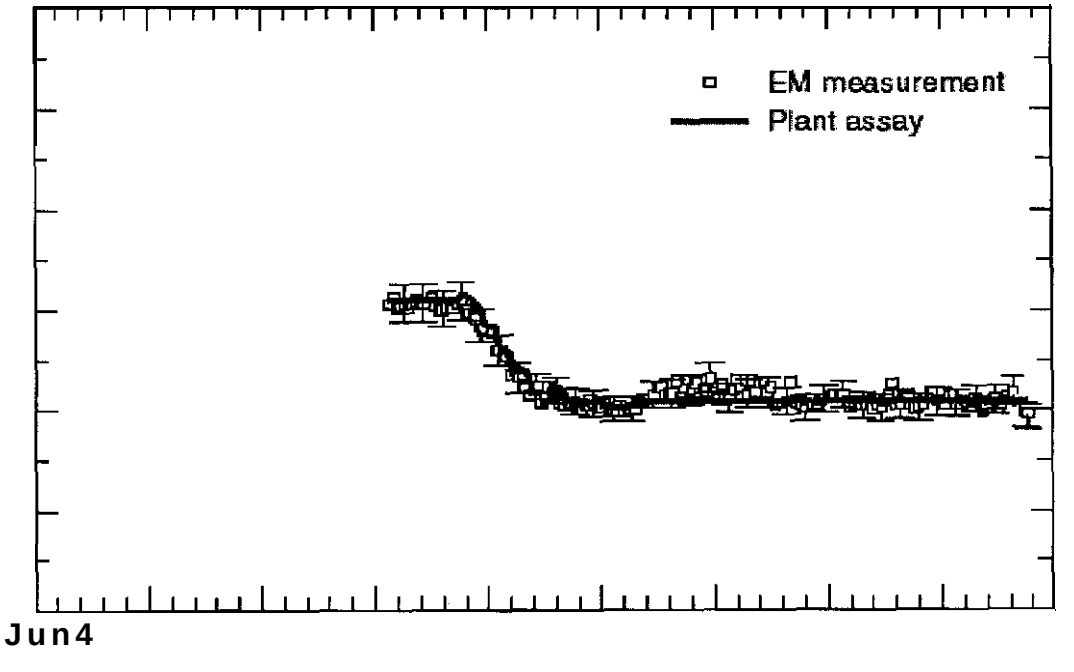
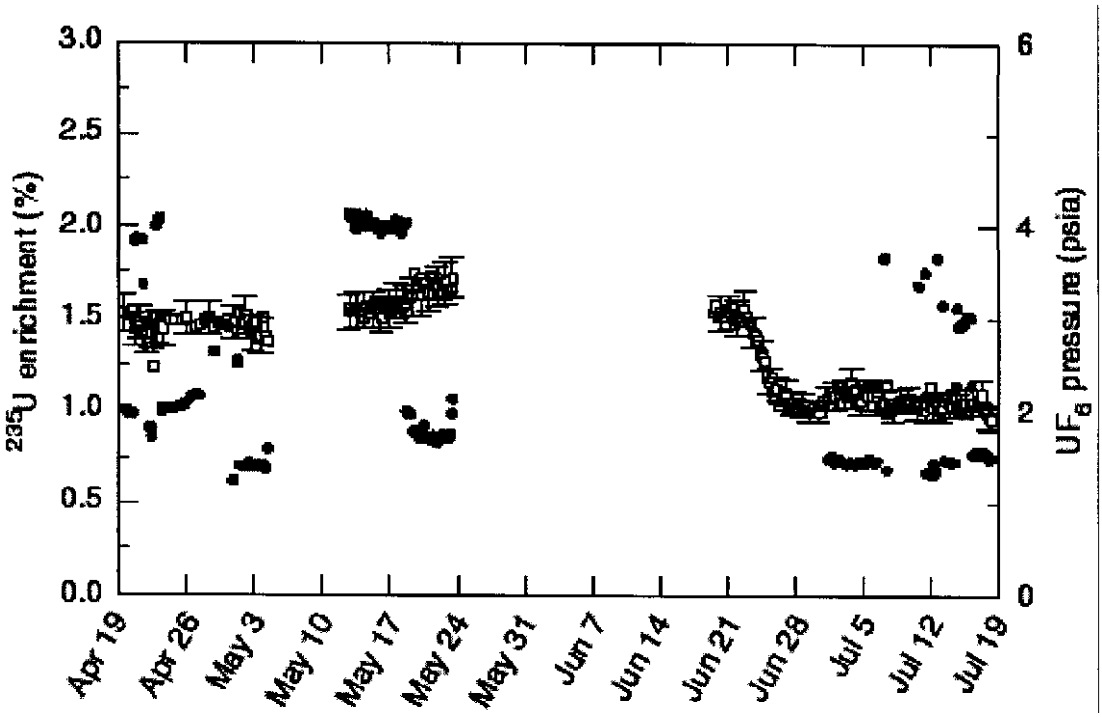
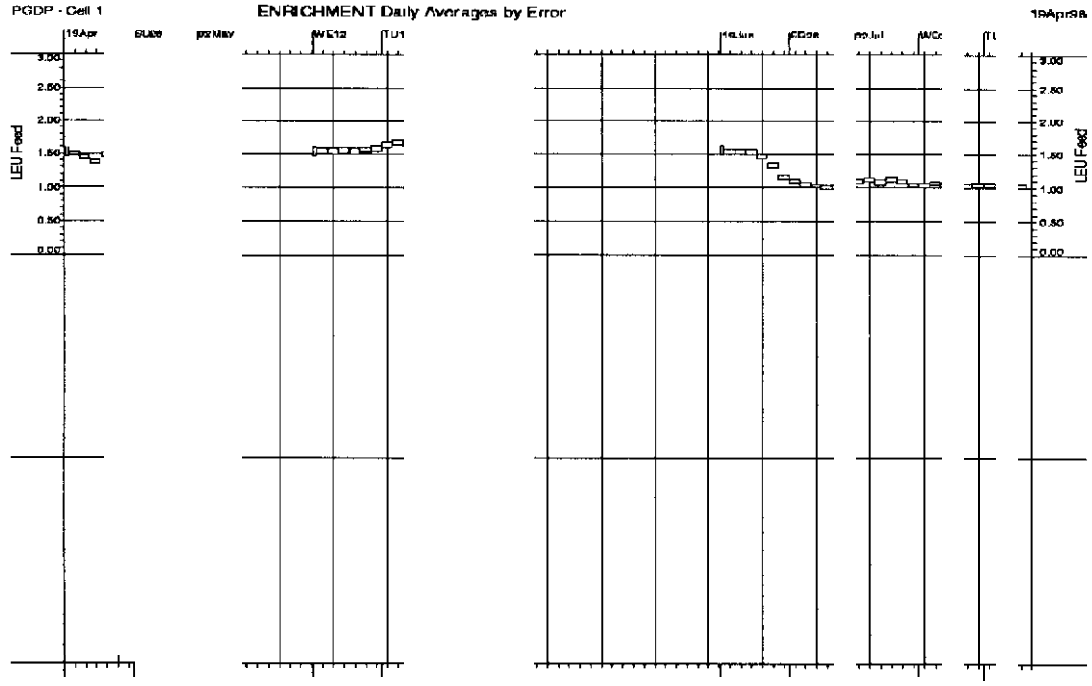


Fig. 2. EM enrichment measurements and plant assays for the period from April 19 to June 4.




3.0
2.5
2.0
1.5
1.0
0.5
0.0
235U enrichment (%)
6
4
2
0
UF6 pressure (psia)
Apr 19
Apr 26
May 3
May 10
May 17
May 24
May 31
Jun 7
Jun 14
Jun 21
Jun 28
Jul 5
Jul 12
Jul 19


PGDP - Cell 1
ENRICHMENT Daily Averages by Error
LEU Feed

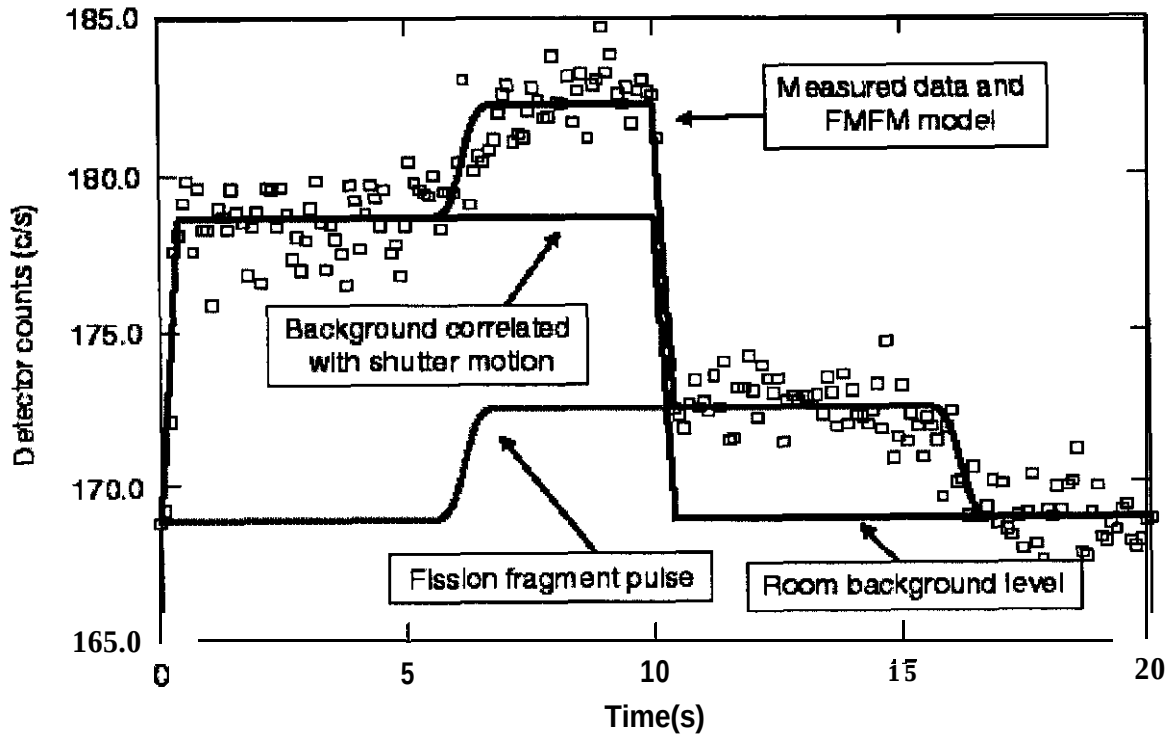
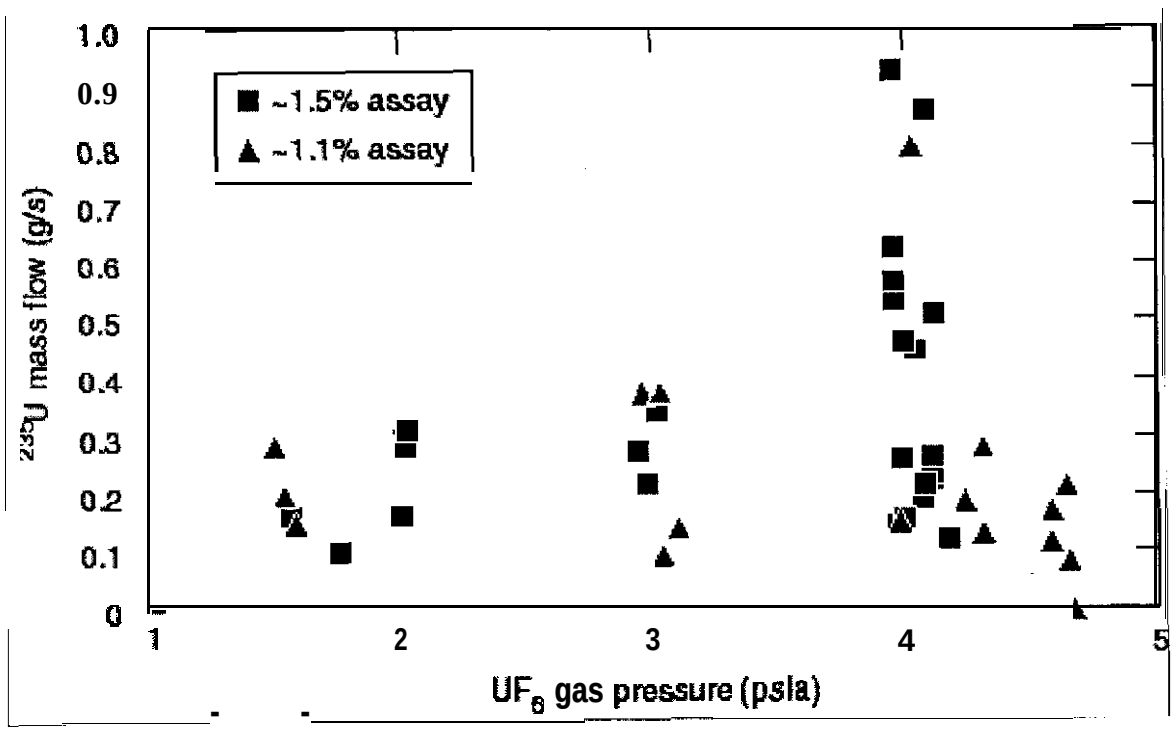
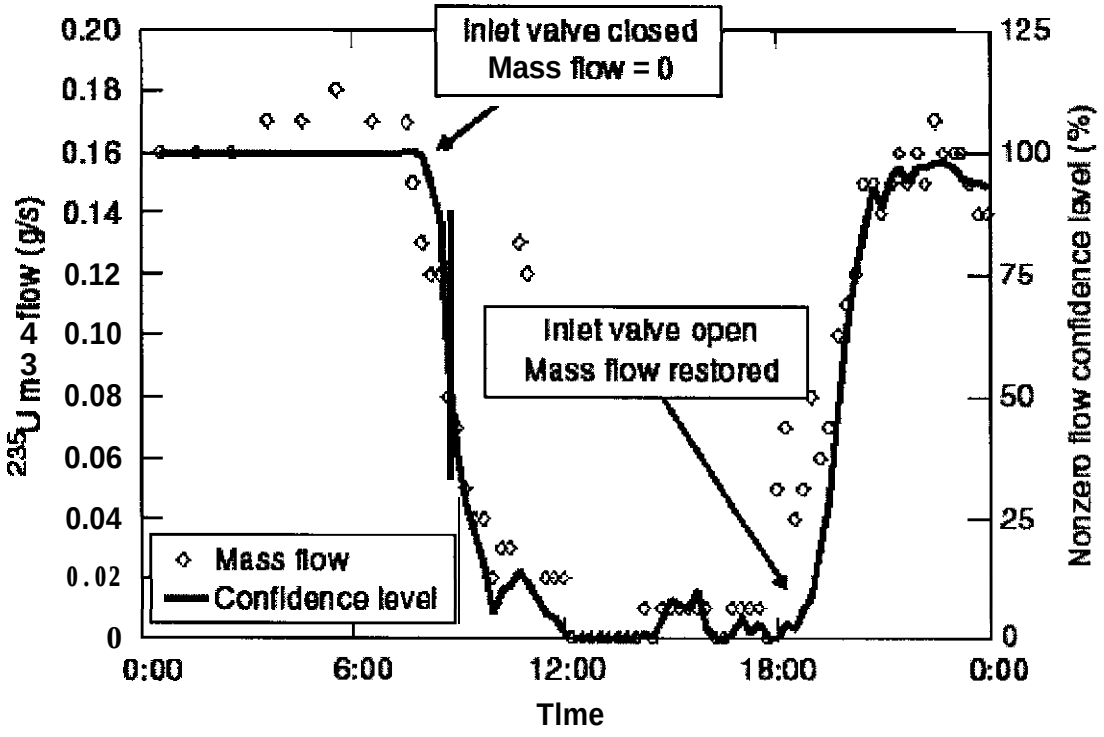
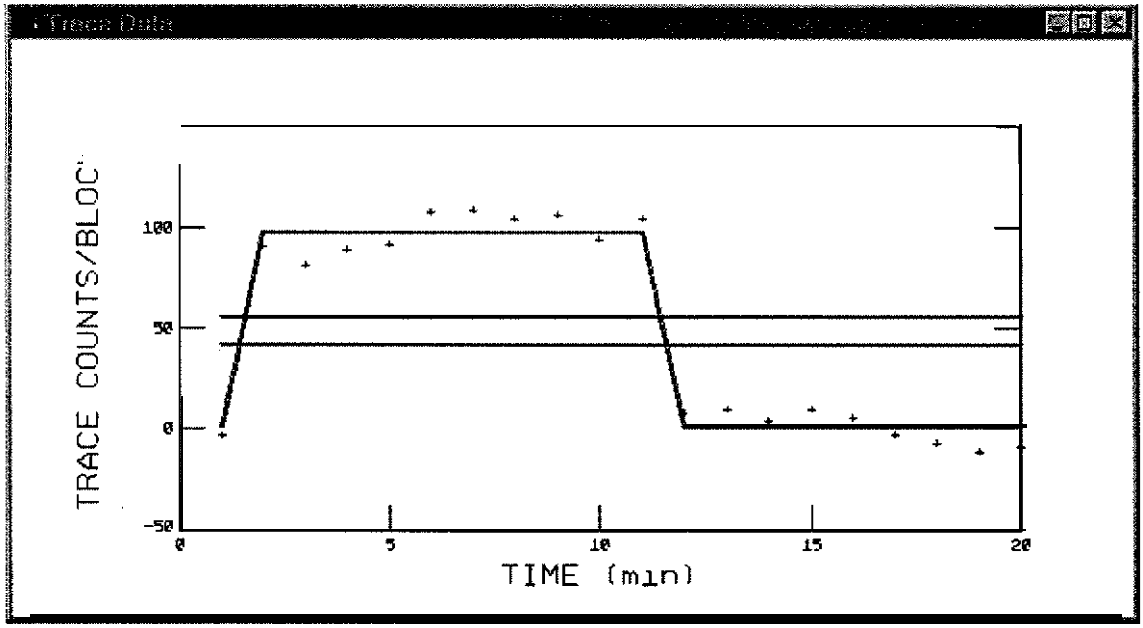


Fig. 6. Typical results of an FMFM measurement, showing the correlated background and fission-fragment-pulse components of the measured signal.




Inlet valve closed
Mass flow = 0
Inlet valve open
Mass flow restored
Mass flow
Confidence level
^{235}U m3 4 flow (g/s)
Nonzero flow confidence level (%)
Time
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
125
100
75
50
25
0
0:00
6:00
12:00
18:00
0:00


TRACE COUNTS/BLOC
TIME (min)
100
50
0
-50
0
5
10
15
20