DEVELOPMENTS IN SAFEGUARDS AS APPLICABLE TO URENCO'S ENRICHMENT PLANTS - AN OPERATOR'S PERSPECTIVE.

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ABSTRACT

A Continuous Enrichment monitor (CEMO), developed under the UK Safeguards support programme for the IAEA has been tested on the Urenco centrifuge enrichment plants at Capenhurst and Almelo. A development model has been evaluated since July 1992 monitoring independently eight cascades at Capenhurst and has shown itself capable of accurately and reproducibly measuring the enrichment level in the product pipe confirming LEU production and detecting periods when UF_6 operation was interrupted. A short term test at Almelo confirmed that a similar instrument could successfully be used on the combined output of several cascades, to monitor the product assay level. The installation requirements for the CEMO present no problems for the latest generation of Urenco technology installed at Capenhurst and Almelo and once installed no plant operator involvement in its operation is necessary.

1. INTRODUCTION

The Urenco centrifuge enrichment plants at Almelo, the Netherlands, Capenhurst, UK and Gronau, Germany, are under safeguards according to the principles agreed at the Hexapartite Safeguards Project (HSP) meetings (1980-1983), based on materials accountancy, containment and surveillance (c/s) and Limited Frequency Unannounced Access (LFUA) inspections. At the time of the HSP meetings, Urenco had successfully operated three pilot plants and had completed commissioning its first two 200tSW/a enrichment plants at Almelo (SP3) and Capenhurst (E21). Construction of two larger plants (SP4 and E22 respectively) at the same sites was in progress. Since that time the 200tSW/a enrichment plant at Capenhurst has been closed after 15 years of operation. The E22 plant at

Capenhurst has been completed with a capacity of 850tSW/a while the plant at Almelo is nearing completion with a capacity of around 1200tSW/a. In addition a new 1000tSW/a enrichment plant is currently under construction at Gronau in Germany. First capacity of this plant came on line in 1985 and current capacity is around 500tSW/a.

Centrifuge and its related plant technology has, in the same period, been extensively developed. Urenco are currently installing their fourth generation of commercial centrifuge, with the development of a fifth generation machine on line for deployment in the second half of the decade. These developments have resulted in uranium enrichment plants which are much more efficient and flexible than the earlier designs in the production of Low Enriched Uranium (LEU) for use in fuel for commercial reactors.

As foreseen at the time of the HSP meetings, considerable development programmes [1,2,3,4] have been undertaken on non-destructive assay (NDA) measurement techniques for use in centrifuge enrichment plants as a potential technique for use during LFUA visits. The experience gained with the development of these techniques for the intermittent application of NDA to centrifuge cascades, formed the basis for the development of a Continuous Enrichment Monitor (CEMO) within the UK Safeguards Support Programme for the IAEA [5], funded substantially by the UK Department of Trade and Industry. Development trials of this monitor have been performed on the latest tranches of capacity installed in the Capenhurst enrichment plant, with additional tests at Almelo. In summary the CEMO has been tested successfully under various combinations of pressures and pipe dimensions present during normal operation of Urenco plants.

Urenco fully supports the development of equipment for the continuous monitoring of the product enrichment assay in centrifuge enrichment plants.

2. DEVELOPMENTS IN URENCO TECHNOLOGY

Following the Treaty of Almelo which enabled the establishment of the Urenco organisation, Urenco operated three pilot plants based on technology developed independently in the three countries. The later tranches of these pilot plants already incorporated improvements, resulting from the interchange of development experience between the three countries. A complete assessment of the performance and future development potential of all areas of the centrifuge and plant technology was undertaken and two designs lines agreed for further development.

The first generation centrifuges installed in the two subsequent 200tSW/a plants built in parallel had a small separative power, so even with many hundreds or thousands of centrifuges installed per cascade there were many replicated cascades in both plants. The area of the cascade halls was also consequently large, typically e.g. 100 x 100m in SP3. Through the development of the next generations of centrifuges the separative power was continually improved by increasing both the length and the speed of rotation of the rotor. The separative power of the currently installed fourth generation centrifuge is an order of magnitude higher than the first generation machines with a further significant increase already demonstrated for the next generation. As a consequence capacity which originally required many tens of cascades can be constructed now using only a few cascades occupying typically 25 x 50m in SP4. Centrifuge mounting and thermal management technology has similarly developed through the generations, encompassing both single and block mounted concepts.

Due to the low growth rate of nuclear power generation since the 1970s, Urenco's plant expansion, based on matching capacity with firm orders, has been slower than originally expected. As a result the two larger enrichment plants at Almelo and Capenhurst have incorporated the latest generation technology as it has become available. The E22 plant at Capenhurst contains all four generations of centrifuge technology while first generation centrifuges remain in operation in the SP3 plant at Almelo and second to fourth generation centrifuge technology is installed in SP4. A trial cascade for the latest machine has also recently been commissioned at Almelo.

3. CURRENT SAFEGUARDS REGIME

All Urenco centrifuge enrichment plants are subject to safeguards based on the conclusions of the HSP meetings. Procedures include monthly inspection visits covering material accountancy with associated c/s measures, including container seals and, in selected areas, video surveillance and an annual Process Inventory Verification (PIV). As agreed in the HSP negotiations, visits to the centrifuge cascade halls are an integral part of the safeguards regime. At Capenhurst this has included the use of an off-line NDA measurement instrument, Cascade Header Enrichment Monitor (CHEM), to confirm the presence of LEU in cascade pipework. The LFUA visits to the cascade area are to verify that no changes have been made to the installation of the process equipment by checking against design drawings/photographs kept on site under Inspectorate seal. This has been assisted by the essentially repetitive nature of the cascade pipework and the large number of similar cascades. These procedures have been in operation for about 9 years and have enabled the Inspectorates to confirm that the Urenco plants have been only producing LEU and safeguards criteria have been met.

However, as the centrifuge plant technology has developed, commercial pressures have led to continuing improvements in the flexibility and efficiency of production of LEU for commercial reactors and to larger enrichment plants. The SP4 plant at Almelo when completed will have a capacity nearly 50% higher and in 20% fewer cascade halls than originally planned. The expanding number and size of nuclear facilities subject to International Safeguards also leads to the need for increasingly efficient safeguards. A continuous enrichment monitor which could reliably confirm the continuous production of LEU in a centrifuge enrichment plant on a go/no go basis would thus seem to be a significant benefit to the Inspectorates. Reliability is, however, essential as any "false" indication that LEU production was not confirmed would involve significant effort by operators and Inspectorates to resolve the apparent anomaly, and would raise unwarranted doubts on the use of the enrichment plant.

4. ENRICHMENT MONITORING

Considerable research work has been undertaken over the last decade into systems for the "intermittent" measurement of the enrichment in centrifuge cascade pipework on a go/no go basis (LEU confirmation). The instrumentation has generally been limited by the need for liquid nitrogen cooling of, e.g. high resolution detectors and the performance has been deleteriously affected by the small diameter process gas pipework in the early centrifuge plants and extensive UF6 deposits present in some of those pipes. The end result has been the need for long measurement times, complicated measurement techniques and considerable Inspector (and associated operator supervision) time to implement measurements. The latest centrifuge cascade pipework diameter is significantly larger than much of the earlier technology, improving the ratio of gas to deposit signal and thus providing potentially more suitable conditions for NDA monitoring.

5. THE CONTINUOUS ENRICHMENT MONITOR

The CEMO, as developed under the UK Safeguards support programme detects the total mass of ^{235}U in the pipe monitored (γ) by measuring the 185.72keV gamma rays emitted by that isotope. The gas pressure (p) is determined from the measurement of the absorption of Ag K x-rays (22.25keV) emitted by a ^{109}Cd source. These two measurements permit the Enrichment (E) to be determined from $E = \gamma \times K / p$ where K is a constant. Both are measured using a common low resolution scintillation detector fitted with a local high voltage generator. The detector is gain stabilised using 88keV gamma rays from the same ^{109}Cd source. This complete package, which can be sealed by the Inspectorates, including lead shielding for the detector, is free mounted on an appropriate length of pipework, requiring only a short length of accessible straight pipework and approximately 350mm clearance in one direction. The connection from this unit, and up to 7 others, to the central control unit consists solely of screened low voltage cable. Each unit has its own 256 channel multi-channel analyser. The central control unit performs all calculations for determining and displaying the mass of ^{235}U, the pressure in the pipe and the enrichment, and the upper (3 σ) statistical bound for enrichment, as well as logging such data and background counts. The complete central control unit, electronics and associated support equipment can be installed in an inspector-sealed cabinet (approximately 1m x 1m by 2m high) located up to 100m from the detector heads.

For the operator the most important points of the design, next to the small spatial requirements, are the minimal services required. The operator only needs to provide a "highly reliable" power supply as the CEMO has a permanent battery back-up covering any short loss of mains power. The gain stabilisation of the detector compensates for the temperature dependence of the detector, permitting operation in an uncontrolled (temperature) environment. The low voltage connection between detector and control unit presents no safety hazard and the low resolution detector requires no liquid nitrogen. Once installed the operator should thus effectively have no further commitments to the routine operation of the CEMO.

5.1 Location

The possible location for the installation of the CEMO within the centrifuge enrichment plant is determined by a number of factors including:

(a) unhindered access by the Inspectorates to both the control module and the detector heads, the latter for checking tamper indicating seals and routine maintenance. This results in a location for the detector head outside the "LFUA" area.

(b) the availability of a length of suitable straight pipework of acceptable diameter and wall thickness, in which deposits and process gas pressures are of an acceptable level; and

(c) potential take-off points between the cascades and the CEMO monitoring point, and, if present, the suitability of c/s measures to cover such situations.

Urenco considers that such locations and conditions exist for the latest technology installed in the enrichment plants at Capenhurst and Almelo. (The latest technology has not yet, but will be installed in the plant at Gronau). At Capenhurst this is on the product header connected to each cascade after it leaves the cascade hall and before the output from several cascades is combined and collected in an assay unit. At Almelo this is on the product header, after the output of several cascades has been combined within the cascade hall in an assay unit header, also after it leaves the cascade hall.

The pipework in both cases is made from aluminium though the pipe diameters and pressures vary widely. External pipe diameters ranging between 120 and 220mm, with wall thicknesses between 4 and 5mm and operating pressures ranging between one hundred and several hundred Pa.

5.2 Operation

Centrifuge enrichment plants are designed for continuous operation and operate under stable conditions during a production campaign to provide product and tails to given assays defined by customer requirements. A change in assay within the cascade flexibility will require new cascade settings and the cascade will come to a new equilibrium over a period of hours. Typically the Urenco centrifuge technology is designed to operate for greater than 10 years without maintenance so no routine planned maintenance cascade "downtime" is expected. Interruptions to production can occur however, e.g due to power cuts, support systems failures etc. These outages are typically very short, mostly lasting minutes rather than hours and are infrequent. Cascade availability is around 99% (time). Provided that the pipe dimensions and normal operating pressure of the pipe monitored are suitable, confirmation of LEU production leaving the cascade hall should thus be able to be obtained from the CEMO effectively continuously. In addition, when mounted on a cascade basis, the CEMO would indicate when and for how long the cascade was off-line.

5.3 CEMO Plant Experience

5.3.1 Capenhurst

Plant experience with an early prototype CEMO was gained in 1989 when a four-detector variant was first mounted on cascade pipework at Capenhurst, since when the equipment has been continuously evaluated and development continued. An eight-detector head development model CEMO was installed in July 1992 on the last eight cascades commissioned and has monitored the product from these cascades to the present day. This has included a joint programme between the developers: AEA Technology (Harwell Instruments) and the IAEA/Euratom Inspectorates. The results have been discussed with the DTI and Urenco. The results not only confirm LEU production whilst the cascades have been on line, but also show that the accuracy of the enrichment measurement under normal operating conditions is extremely high and that even with 3 σ statistical spread the "LEU not confirmed" indication will not be breached in error. Similarly the pressure measurement has reliably detected those process gas outages that occurred.

The detector on the eighth cascade was installed when the cascade was in vacuum before UF_6 was introduced. During UF_6 commissioning of the cascade, the 22keV x-ray transmission was reduced as expected by a combination of both a deposit build up and the process gas. Later gas outages indicated that the deposit signal was significantly higher (more than twice) than that of the gas signal. This required that the CEMO calibration constants be adjusted after commissioning. With the equipment accessible at all times to the Inspectors, such corrective measures could be taken during their next visit. A typical trace from a detector showing the γ (^{235}U), pressure and resultant enrichment levels is shown in Fig.1.

5.3.2. Almelo

The cascade hall containing the latest technology in the Urenco SP4 plant at Almelo is constructionally different to E22 in Capenhurst. A location was identified on the header pipe where the combined output of several cascades left the cascade hall. Application on a group of cascades, rather than on individual cascades, has the potential to reduce capital investment in equipment, but is less of a benefit if there are possibilities for removal of the process gas before the monitor. In this case, additional c/s measures would be necessary to cover these possibilities to gain the full benefit of the CEMO. The pressure at this location is significantly lower, but the pipe has a larger diameter and thinner wall, than at Capenhurst. The first parameter is detrimental to the accuracy of the pressure measurement, the latter two parameters beneficial. Urenco sponsored a short term trial of a CEMO with the same software and basic hardware (though with an adapted source/detector housing) under these conditions on the plant at Almelo. To gain information on the sensitivity of the measurements while not interrupting the production campaign in progress, the CEMO was mounted on both the tails header, nominal assay 0.3% ^{235}U and the product header, nominal assay 4% ^{235}U, which in this location have identical pipe geometries and material. The pressure in the tails header is approximately twice that in the product header. The results are summarised in Fig. 2. Although these tests were short term, the indications are that the spread in measurements (over 2 days) was similar to that expected from counting statistics and thus erroneous indications of LEU not confirmed should not arise. The tests also confirmed the benefits of larger diameter thinner wall thickness pipes to the performance of the CEMO.

During these tests at Almelo, a check could be made to determine if the use of UF_6 from reprocessed ex-oxide material in cascades monitored by CEMO would adversely affect the measurements. A high resolution germanium semi-conductor detector was mounted on the pipe set to detect gamma rays with energies up to 2000keV. The background spectrum and that from the product pipe indicate no peaks liable to interfere with the operation of the CEMO (Fig.3).

6. CONCLUSIONS

Long term trials of the Continuous Enrichment Monitor on individual cascades of the latest generations of technology installed in the Urenco centrifuge enrichment plant at Capenhurst have confirmed that the instrument will reliably confirm "LEU" production while the plant is operating under normal conditions. The instrument will also detect reliably instances when process gas is removed from the cascade. Initial tests suggest that a similar conclusion with respect to the "confirmation of LEU production" can be drawn for the Urenco enrichment plant at Almelo while monitoring an assay unit (group of cascades).

Apart from requiring a short length of suitable pipework, a small cabinet and a reliable power supply, the CEMO makes no demands on the operator during routine operation.

Urenco would welcome the use of the CEMO by the Inspectorates as a reliable addition to the current range of safeguards techniques applied to the latest generations of technology installed in current and future Urenco centrifuge enrichment plants.

7. REFERENCES

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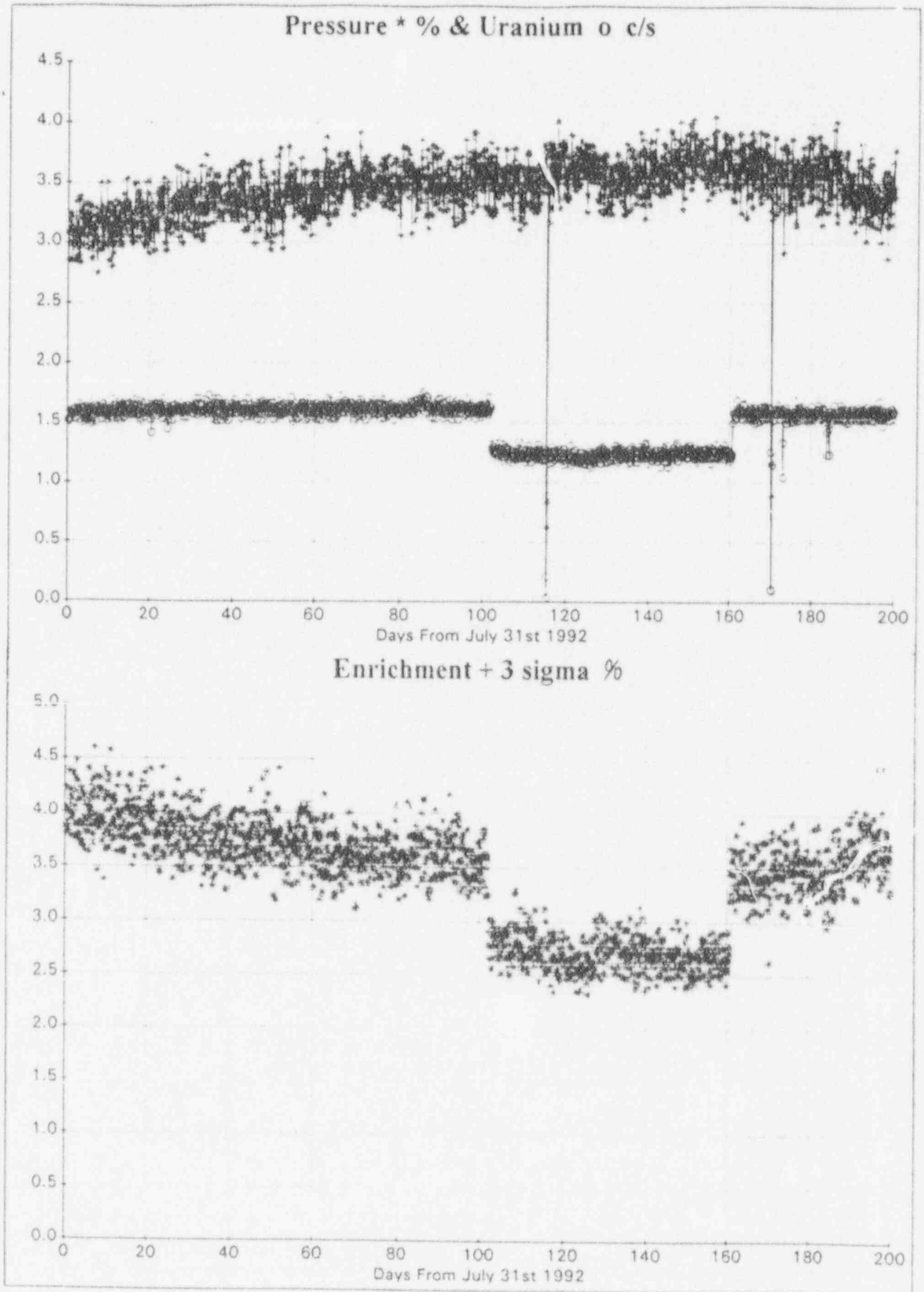

Fig. 1 γ (^{235}U) and x-ray absorption (pressure) data from one CEMO detector head mounted in Capenhurst for the period after July 1992 and the resultant calculated enrichment + 3 σ (%).

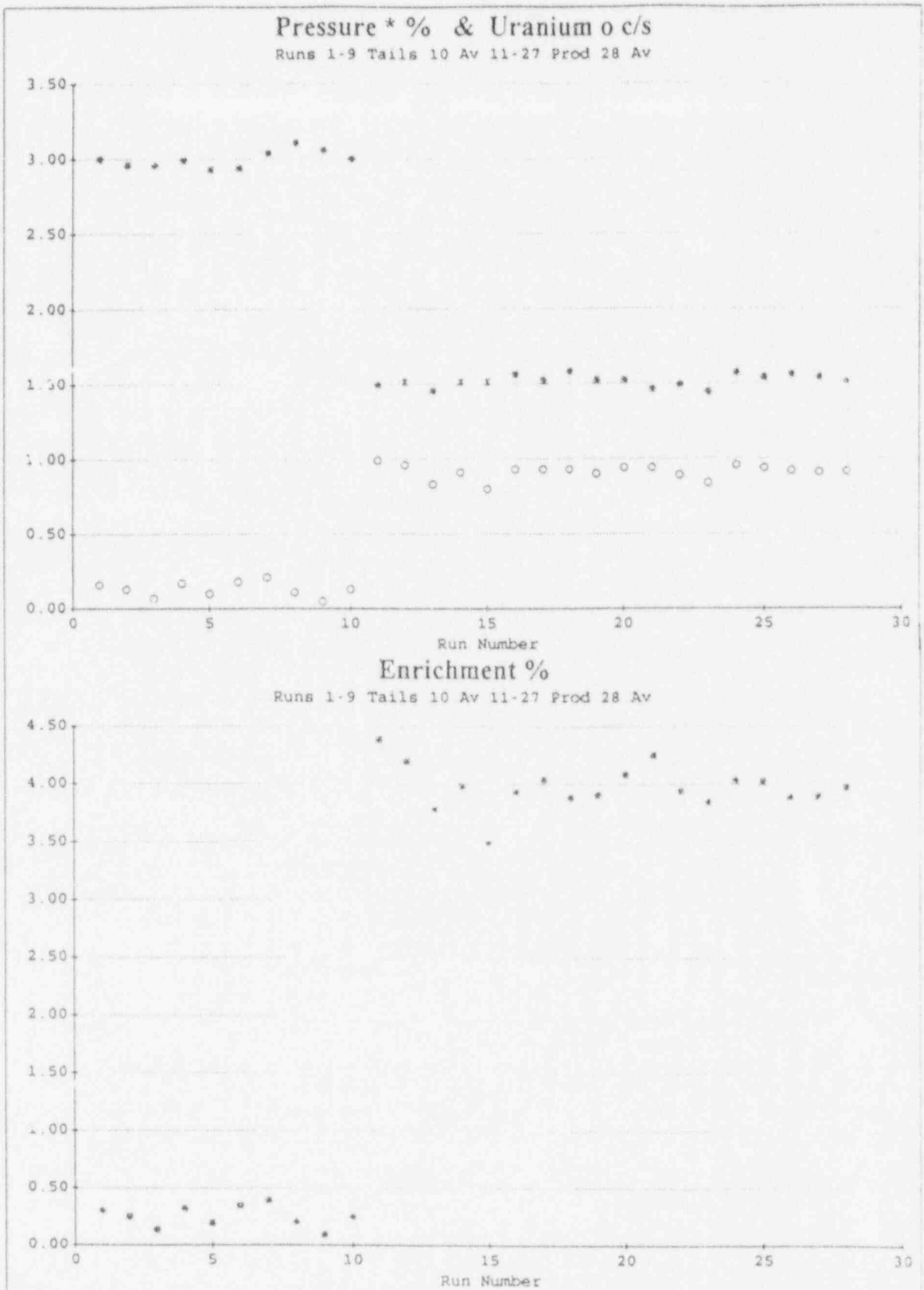

Fig. 2 γ (^{235}U) and x-ray absorption (pressure) data from the single CEMO detector mounted on tails and product pipes at Almelo for 1 and 2 days respectively and the resultant calculated enrichment (%).

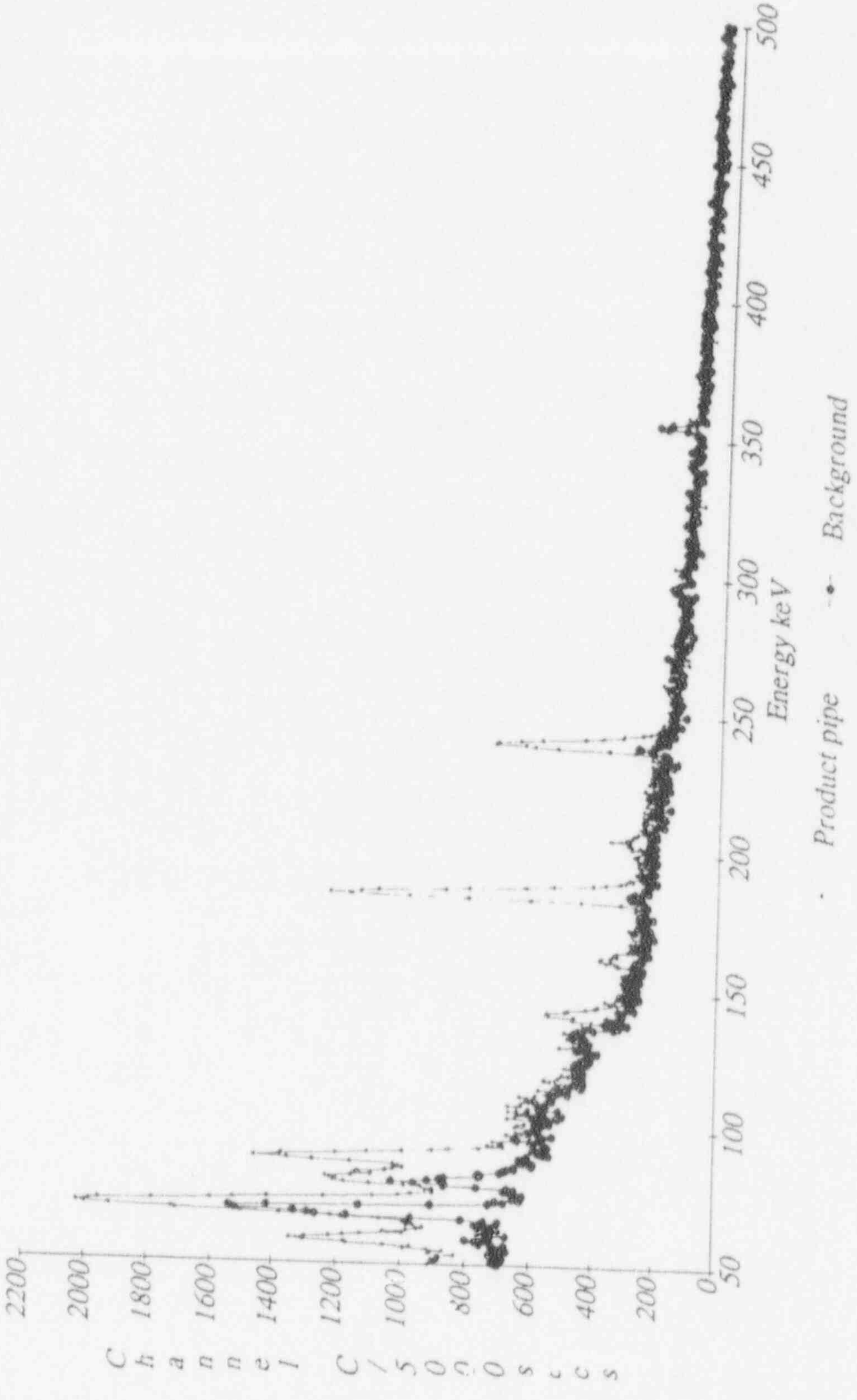

Fig. 3 High resolution spectra from background and product pipe containing ex-oxide reprocessed re-enriched product.