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Centrifuge technology: the future for enrichment

Pat Upson

Introduction

After many years of research into the alternative possible methods for enriching uranium, it now appears that each of the major players have reached a common conclusion, that high speed gas centrifuges hold the key to the future. Alongside the recent announcements that the atomic laser enrichment programmes are being brought to a halt, there have been new proposals to revive the development of the gas centrifuge. Urenco have had a continuous development programme for more than 30 years and now have a lead cascade of the latest generation of machines in operation (their sixth generation). The strategy and risks behind Urenco' s past development programmes are discussed in this paper, together with the Urenco view of the future strategy for development of this technology.

Urenco's History of R&D

Urenco development began in the early 1970s following its formation from three national programmes, all based on the concept of a lightweight rotor operating on pin bearings and magnetic top bearings. Each of these programmes, however, was based on different choices of material, diameter, length - from sub to supercritical - and operating speed, providing a wide base of experience on which to develop a centrifuge for commercial operations. An initial evaluation identified two lines with the greatest potential for economic deployment and these were pursued whilst marketing operations were commenced. This development potential was based upon the possibility of combining improvements in speed, arising from the use of materials with higher specific strength, and length, from improved understanding of supercritical rotors, with separation efficiency improvements. The slow development in the market gave the space for a comprehensive development and qualification programme for these centrifuge lines and for the assessment of the associated manufacturing techniques before these new centrifuges were put into production.

Had Urenco been under the pressure of having a rapidly growing market demand, or even the need to replace an existing enrichment plant, we may have taken a different approach. Time or capacity pressure could have led to the decisions either to shorten R&D programmes and introduce new designs before they had been fully proven, or to have taken much larger steps forward. As our programme has continued, capacity expansion has put more pressure on getting the latest generation of centrifuge on line as early as

possible. This has put time pressure on resolving problems which have been highlighted relatively late in the qualification phase of the programme; these have mostly been materials-related, affecting either short or expected long term performance. The wide basic R&D programme undertaken throughout Urenco's existence has provided the background knowledge to successfully introduce solutions to these problems, without significant delays. It could also have led to perceived requirements to aim for a larger step in output, with greater increase in lengths or speed between the generations when our experience with dynamics and/or materials was insufficiently developed. Our initial development was, however, stimulated by the competition between the three development teams to achieve the most technical advances. The superiority of the no-maintenance philosophy over larger diameter, longer centrifuges requiring maintenance, was never in doubt.

It would be nice, looking back, to be able to say that our development was the result of a well considered strategic approach. It was, but with a lot of luck associated with it. As we were starting out from zero capacity and sales, we were able to match the market growth with a very conservative approach to proving every step well before it had to be applied in production use, and were able to take small steps at a time and introduce each new generation as and when it became available.

In this respect, we have become the victim of our own success. We reached the point in the early 1990's where we were in a different market position, given that our cost base was no longer in touch with the market price requirements, yet our technical developments were still coming forward, and there was pressure to introduce a new machine, just because it was technically possible. The reorganisation of the Urenco Group in 1993 recognised the fact that market pressures would have a much greater impact on our business than the introduction of new generations of centrifuges.

This has caused us to re-evaluate our R&D policy and to take more account of the economic benefit, rather than just focussing on the technical benefits, before we undertake the development programmes. It has caused us to make a major shift in our R&D strategy for the future, in that we no longer see further generations of completely new machines being developed, as has happened in the past, where we would undertake a multi-year programme to develop significantly longer or faster centrifuges, with every confidence that the outcome would be successful. Our future programme is based much more on a series of shorter projects aimed at improving specific aspects of the current centrifuge, either by manufacturing improvements to reduce the cost of manufacture, or by taking advantage of improvements in materials. In either case, the projects are evaluated from an economic point of view, to ensure that the lifetime cost improvements actually pay back the money committed to undertake the research, and from a technical point of view, to ensure that the improvements can be introduced as early as possible within the manufacturing programme, as part of the current centrifuge generation.

This really says that we have reached the end of our series of new centrifuges in terms of length and speed. We will move forward with a series of improvements - mark 2, mark 3, mark 4, etc. Programmes that bring cost reductions in manufacture, or extend the lifetime, but that can bring these benefits within 2 or 3 years, are seen as having a better and lower risk return than a new generation of uncertain timescale and result. A 10% improvement in manufacturing cost is as valuable as a 10% improvement in output, and does not carry the same risks as introducing a new machine.

Development Programme Philosophy

To expand this further, as I have noted above, in the past, Urenco has always taken a well considered and step by step approach to developing each centrifuge generation. We have set out the development programme in three stages: R&D, Qualification and Production Demonstration.

- *R&D*: This includes all the theoretical and design studies, testing of all new materials, manufacture and spin testing of a small number of components, and building and testing of typically 10 or 20 centrifuges.

- *Qualification*: The qualification phase is employed to prove that the centrifuges will operate successfully long term under all plant design conditions. Manufacturing routes have to be established and proven by the production of typically 100 to 200 centrifuges.

- *Production Demonstration*: This involves the increase in manufacturing rates from the small demonstration levels needed for qualification, to the full production requirement of several thousand per year. This culminates in the building and operation of a lead cascade; or demonstration cascade, in which all the final designs and modifications are brought together. Where the need for modifications is identified, these will all be tested and backed up by appropriate theoretical studies, so that the lead cascade has the best possible chance of successful operation. Only after a period of around 6 months, operation of the lead cascade, would a decision be taken that the new generation is successful and should then be adopted for production use.

Generally, the overall programme has taken 7 to 8 years; 2 to 3 years for R&D, 2 to 3 years for qualification, and 2 years for production demonstration. However, as we have reached the latest generations, the programme timescale has become more and more difficult to maintain.

In the past, as and when the latest machine has been demonstrated successfully, it has been introduced at the earliest opportunity as a step change. This has always carried risks, in that the change over can bring "teething problems" where the new manufacturing route takes longer to effect than had been planned, or throws up one or two new problems in the ability to meet the stringent specifications, that were not so obvious in the demonstration phase. Again, in the past, when our expansion programme gave time for an occasional pause to ensure that the new generation was brought in successfully, there was time to resolve the teething troubles. Given the need to maintain an ongoing plant construction programme over the next few years, this policy will be modified, in that the switch to TC21 from TC12 will be phased, with a period when both types of machine will be in production, with the TC12 initially taking the production lead, but, as experience is gained, production of TC21 will increase and TC12 phased out, perhaps over a 3 year period.

Development History

Starting with the original pilot plant work, Urenco developed two generations of composite overwrap centrifuge and these were brought into operation in our enrichment plants, in parallel with the all-metal design. The main early concern was to increase the

peripheral velocity and the length to diameter ratio (l/d) and, as the all-metal designs were limited by the specific strength of the materials, these exploited the benefits from improving the l/d ratio, bringing an increase in this of a factor of around 6 in the third generation machine, with only a modest increase in the peripheral velocity.

The resultant (relative) increase in centrifuge output has been published previously, but is given again here to illustrate the development story (Figure 1). This indicates an approximate doubling in separative power as each new generation has been successfully brought into operation.

With hindsight, this can be seen to have been the appropriate target for each new generation; in fact, the targets perhaps should have been set at a rather higher level. Given the extensive programme of developing and testing new materials for each new generation, followed by long proving programmes, and given the capacity expansion which has actually been possible in the market, Urenco has found that the "payback period" for the R&D expenditure was progressively longer as each generation was brought on line.

During the early 1990s, when the reorganisation of the Urenco Group was being prepared, the targets for the future development programme were set. This was for a series production machine with more than double the output of the, then, series production machine, the TC12. This has now been achieved in practice, but the programme has taken longer than originally planned. Consequently, although the machine will bring an economic improvement over the existing TC12, and will pay back its development costs, the payback is following the pattern from the past – each machine taking longer to pay back. It is now a real risk that development of further new generations, on this same philosophical basis, would pay back only if the expansion programme increased dramatically, or if the target output increased dramatically.

The development programme for this latest generation of centrifuge is now coming to a successful completion. We have many machines which have been running in our life test field, with some machines already having completed 4 years' operation. The final proving tests on individual components have been successful, and we have a half cascade in operation in the Gronau plant, which has been running for over a year. The lead cascade did give us some problems, in as much as there were some early failures which we investigated – by stopping the cascade, taking out some failed and un-failed machines, and stripping down and examining the individual components – and found that our specifications on materials were inadequate to prevent some operating failures. We have solved the problem by tightening up the specifications, and are now building the second half of the cascade.

Assuming that this second half runs successfully, and we are very confident that it will, we have one further hurdle to overcome – the economics. So far, we have built around 1000 of these TC21 centrifuges. They do have an output of more than double that of the TC12, but they are much more complicated, with more components, and specifications which are more difficult to reach. We are reviewing the current manufacturing costs and taking a view from our previous experience as to what the real manufacturing costs will be when we start to manufacture at production quantities. There are also several potential additional plant cost savings when we switch to the TC21 – with less than half the machines needed to produce the same output, the building will be smaller, there will be

fewer mounting positions, half the cascade pipework, etc. All of these issues are being reviewed and when we have confirmed that the complete TC21 cascade is going to give a better economic outcome than the existing machine, we will switch our production over to the new generation of machine.

One area that one might have expected to have become a limiting factor, with increasing difficulties as the centrifuges have become more complex, is that of sensitivity to seismic activity. This has not proven so in practice. Whilst the Urenco plants are not situated in major seismic zones, the existing plants have suffered a few minor seismic shocks; the most significant being in the late 1980's at the Capenhurst Site, when a few tens of the first generation centrifuges crashed after a tremor based in North Wales. The centrifuge designs have always taken account of the potential seismic activity, and it has been possible to ensure that the latest machines are no more at risk than previous generations.

Figure 2 shows the R&D improvements Urenco has made over the six generations of machines. The latest, the TC21, has a separation factor of over 50x the early machines, and a length an order of magnitude greater. A major factor contributing to the practicality of these increases in rotor velocity and length has been the development of high quality, low voidage and low imbalance filament winding technology. This, combined with the low density of the material, has minimised the forces on the bearings and dampers, thus easing the development risks in these areas. The low-density material has eased handling difficulties, enabling rotor production horizontally and installation vertically to be continued.

The technical improvements from Urenco's first to sixth generation are well demonstrated in Figure 3, showing a block of the first generation machines against a sixth generation machine. The block contains several tens of centrifuges, yet has about the same separative power as the single machine.

The future for development within Urenco will be to concentrate on improving the latest centrifuge as a mature technology – to achieve cost reduction and manufacturing improvements which can be developed and proven as discrete projects and introduced into the machines then being manufactured as and when they have been qualified for use.

Other Potential Centrifuge Development Proposals

We have heard in the past year of the possible approach in the USA of a new development programme based on the previous GCEP machines, which would lead to a new generation of centrifuges which would be much larger and, perhaps, faster than our TC21, and within Urenco have discussed whether we could consider such an approach. We could, and would even conclude that such a programme could be brought to a successful conclusion. However, the current view in Urenco is as above, that such a programme with Urenco's development and operating philosophy would be too close to the scope of materials currently available, and that the only possible approach would be that based on the GCEP concept, with the machines having to be regularly taken out of service for maintenance.

Such a programme would be achievable, but would require significantly more development and qualification testing before it would give a centrifuge that we would be confident of being able to manufacture in production quantities, without considerable

concerns about the costs and eventual operating lifetimes. We would consider that such a programme would, even if it was successful at each stage, require at least 8 to 10 years, and would cost more than the economic return that would be gained from replacing our TC12 or TC21 by such a machine.

Of course, if one did not have access to Urenco' s centrifuge technology, and needed a replacement technology, then the risks of undertaking such a programme, from both the cost and timescale point of view, could be worth taking. However, as has been said on a number of occasions in the past, Urenco technology could be made available, if the right commercial terms were to be agreed.

Conclusion

The philosophy in the Urenco Group to R&D in the past has always been to carefully develop through testing of new materials, to manufacture and testing of individual components, through to successively running single machines, then demonstration cascades. This has given the successful introduction of each new generation, with only limited risk – the technical performance has been known, prior to making the decision to step forward.

As the generations have been introduced, the technical difficulty and need to push the design closer to its operating limits have become greater, and it is now clear to Urenco that the latest generation centrifuge, the TC21, is the last in the family which started in the 1970' s.

The TC21 has now been operating for more than 15 months in a lead cascade, and is operating very successfully. If this performance continues, and when the economics of manufacture have been confirmed, Urenco will be taking a decision within the next 18 months for a phased introduction of the TC21 in our production plants.

Further generations of centrifuge would be possible, but would probably take more than the 7 to 10 years which Urenco has achieved in the past, and would lead to plants that would be less flexible in operation. With such a mature technology, Urenco is now following an R&D philosophy that will focus on improvements to the latest generation of centrifuge, the TC21, which will enable a series of improvements to be put into production use, as and when they are proven. In this way, Urenco is confident of maintaining its current position as the operator of the most advanced and lowest cost technology, well into the future.

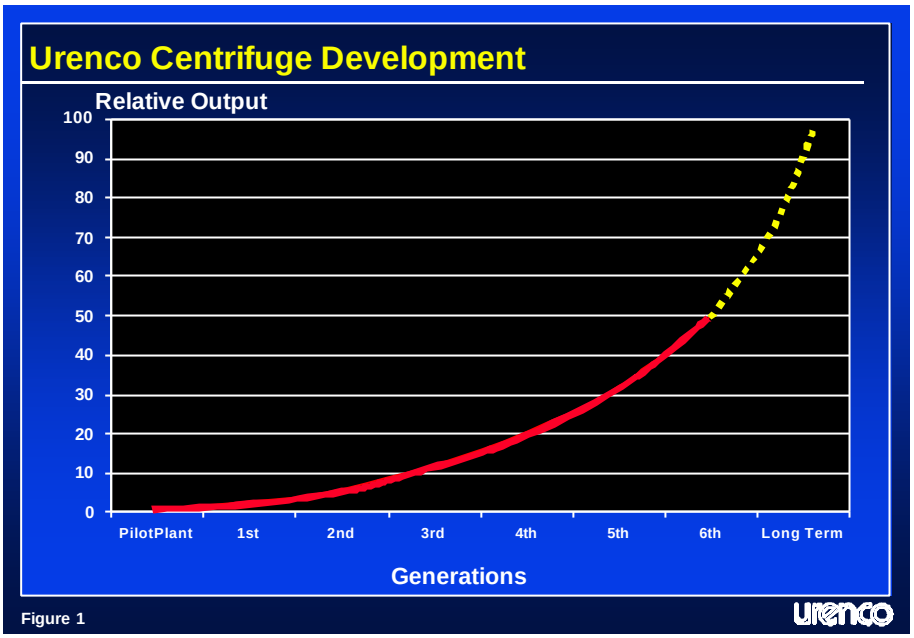


Figure 1

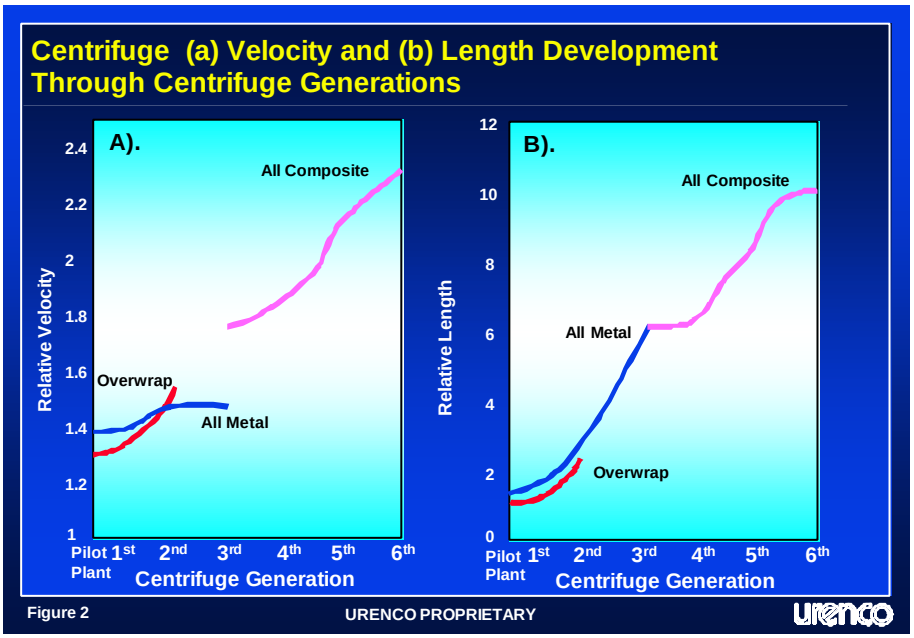
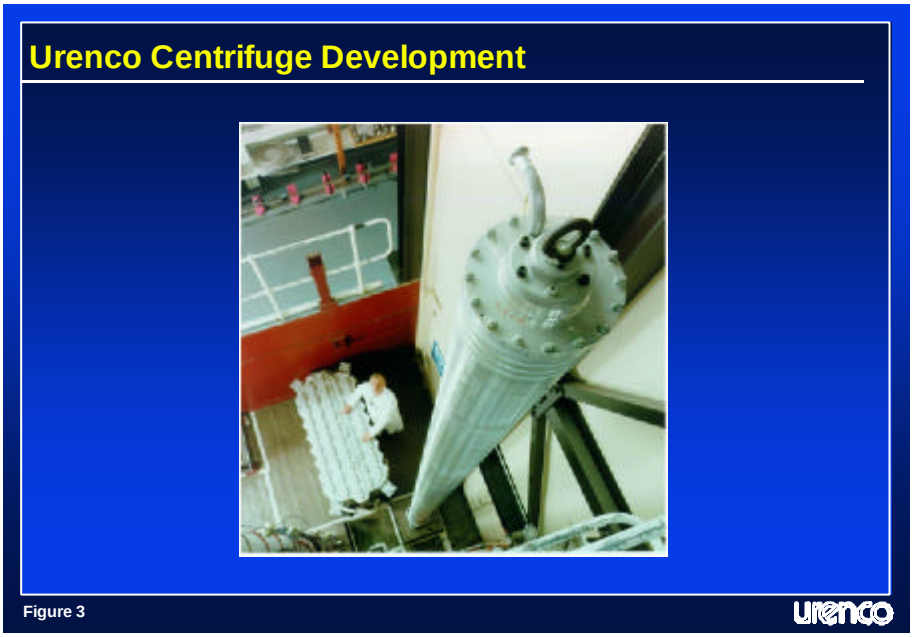


Figure 2


Urenco Centrifuge Development
Figure 3
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