Proceedings HTR2006:
3rd International Topical Meeting on High Temperature Reactor Technology
October 1-4, 2006, Johannesburg, South Africa

HTR2006 Paper number B00000077

COMMISSIONING EXPERIENCE WITH BOTH THE LABORATORY COATER AND THE INITIAL FULL SIZE COATER AT THE PBMR FUEL LABORATORIES

J C BARRY (PBMR Fuel Development Group under the auspices of the South African Nuclear Energy Corporation)

ABSTRACT

A scaled-down coater was established a number of years ago, while the initial full size coater was recently completed at the PBMR Fuel Laboratories. These are used to develop the technology to coat UO_2 kernels, so as to produce particles that are equivalent to the particles produced by latest German HTR technology. An overview of the most important and interesting commissioning experience gained over the past 6 years will be presented.

INTRODUCTION

In 1999 work was begun to build a one-fifth scale (1 kg UO_2 charge; 20 kW power consumption) coater at the Necsa laboratories.
This was embarked upon in order to:

- Gain understanding of coating processes so as to produce particles that are equivalent to the latest German HTR technology;
- Train personnel; and
- Provide initial material for the Quality Control and Fuel Sphere laboratories, for the further development of their methods and processes.

Only depleted (< 0.7% Uranium-235) UO_2 kernels have been used in the small coater.
As far as possible, given the 1 kg constraint, the intention was to make the small coater to reflect the German technology. At the stage that this was begun, only limited information was available.

In 2003, PBMR decided to build a "full size" (5 kg UO_2 charge; 110 kW power consumption) coater, also at the Necsa laboratories. This coater was designed to be the prototype for the coaters of the same size in the planned Pilot Fuel Plant (PFP). The 5-kg coater is therefore also known as the "Advance Coater". Its goals are to:

- Mitigate the risks for the PFP. Coaters and coating technology are seen as the biggest risk for the PFP due to their complexity. Other coating systems copy inherently simpler proven German systems. The coater was intended to be as close a copy of the German coater as possible, so as to be able to produce fuel that is equivalent to the German fuel.
- Train production plant personnel, as the coater will operate eventually with depleted (< 0.7% Uranium-235) UO_2 kernels.
- Enhance the understanding of coater processes and of coatings behaviour.
- Demonstrate modifications intended for the production plant that can enhance its productivity.

The coaters are usually referred to by their nominal charge size in an attempt to remove ambiguity as to which coater is being referenced. Thus reference is made to a "1 kg coater" and to a "5 kg coater".

Both of these projects proceeded through the usual phases of:

- Concept Design.
- Hazop.
- Detail design and NNR licensing for "Construction".
- Procurement and Manufacture.
- Assembly.
- Commissioning (presently this is the stage which the 5 kg coater has reached).
- Operation (so far only the 1 kg coater has reached this final stage).

This paper deals with aspects of the commissioning of both coaters.

COMMISSIONING OVERVIEW

Commissioning is carried out in distinct phases – "cold" and "hot", each with its own NNR licence. These differ in the usage of radioactive material: "cold" refers to all work done without UO_2 kernels while "hot" refers to all work done with UO_2 kernels.

Commissioning of both coaters is carried out identically. Distinction can be made between the following three sequential phases that are followed progressively. Each stage is only begun when the previous is fully completed. These phases are:

- Check that the plant is built properly
- Check that systems are operational
- Attempt coater runs.

The first phase, that checks essentially whether the plant is properly built, comprises actions such as:

- Factory acceptance and site acceptance testing of individual items.
- Checks that the plant is built as per documentation, P&IDs and specifications.
- Calibrations carried out where necessary.
- Checks that all safety systems are working.

The second phase focuses more on the systems being operational and usable. Some of the matters addressed here are:

- Heating cycles.
- Vacuum integrity.
- Systems working together.
- PLC and SCADA operational.
- Instrumentation correctly wired.

The third phase essentially has to do with the whole plant running in synchronicity. Coater runs are performed which are sequentially more sophisticated. The next level is only begun when everyone is satisfied that the results from a previous run are as desired. These levels are:

Sequence of runs	Gas used	Heating applied	Simulation kernels used
1	Only argon	No	No
2	Only argon	Yes	No
3	Only argon	Yes	Yes
4	All process gases	No	No
5	All process gases	Yes	No
6	All process gases	Yes	Yes

The underlying philosophy of this method of sequencing was:

- Safety is paramount.
- First use inert gas to check all systems.
- Then introduce heating as the "perturbation" of the systems.
- Finally introduce kernels as a further "perturbation" of the system.

Simulation kernels were used from a safety point of view. Unfortunately there is no readily available material that mimics UO_2 kernels sufficiently well. The properties that such kernels should have are:

- Hard and mechanically robust (handle like UO_2 kernels).
- Low cost (many kilograms are needed for tests).
- Same size as the UO_2 kernels that will be used in later work (to properly test the sampling, loading and gas flows).
- Same density as the UO_2 kernels (to test the fluidisation of the bed).
- No reactivity with the process gases or carbon internals especially at elevated temperatures. They must also not change or deform at these elevated temperatures.
- The variation in size in a batch of such particles must not be very great. Many materials whose particles are in the right size regime, have such a large variation in particle size that either tedious sieving of the particles is required or the variation is just too large to be usable.
- Roundness of the particles is necessary to achieve good fluidisation. This is usually not given in the manufacturer's characteristics of such particles. The UO_2 kernel specification is quite severe on this. Much material available commercially has poor roundness.

The criteria listed above were used for the selection of simulation kernels to be used. Materials that were considered as possibilities for usage were: titanium, zirconia (ZrO_2), zircon ($ZrSiO_4$), alumina (Al_2O_3) and hafnia (HfO_2). None of these materials complies with all of the criteria listed above.

The same mass of the bed to be fluidised can be achieved by simply loading more (or fewer) particles.

The same particle mass as that of the UO_2 kernel can be achieved by changing the size of the kernel (UO_2 kernels are nominally 500 microns in diameter), but this brings its own issues. Since the coaters are initially operated with parameters (judiciously adapted in the case of the 1 kg coater) based on German coaters with UO_2 kernels, the results obtained with simulation kernels cannot be expected to be the same, yet surprisingly good correspondence is obtained to the required particle properties. When using simulation kernels, the idea was never to produce correct layers in all aspects, but rather to get the coaters safely fully operational so that the UO_2 kernels can be loaded.

There is nothing like the real thing (UO_2 kernels) for operations, thus the necessity of "hot" commissioning.

Timelines for the two coaters are reflected in the following table:

1 kg Coater		5 kg Coater
April 1999	Basic Design ready	September 2003
June 1999	Hazop	July 2004
April 2000	Detail Design complete	
May 2000	Construction actions begin	September 2005
September 2000	"Cold" Commissioning begins	May 2006
September 2002	"Hot" Commissioning begins	October 2006 (?)
January 2004	Routine Production Possible	April 2007 (?)

SOME DETAIL ON COMMISSIONING OCCURRENCES

It is not the intention to bore one with all the usual commissioning matters, but rather to pick out some of the interesting, exciting and unusual experiences.

- Gas diffuser in the 1 kg Coater

  Initial parameters were estimated from details of the German experience. It was necessary to adjust the gas diffuser in order to obtain proper fluidisation. Poor fluidisation shows itself in the formation of "doughnuts" which are rings of material made up of cemented together coated and partially coated particles.

  There are a number of inter-linked parameters affecting gas flow:

  - Number of holes in the gas diffusor
  - Relative distribution of holes
  - Size of holes
  - Angle that the gas enters the bed

  - Ensuring reproducibility of the gas distributor as each is replaced after each run (QA)

  The differences between an effective distributor and a distributor that gives poor results are very small. If fluidisation is not good, then statistical process conditions deteriorate and layers are very non-uniform throughout samples. The optimisation was done by experimental modelling using room temperature gas and simulation kernels, followed by using the optimum designs in the coater. From the results obtained, the best distributor design could be chosen. In the 5-kg coater, the same issue did not arise as the Germans had already derived an optimum arrangement.

- Cracking/Breakage of Graphite components

  Issues were:

  - Handling heavy components - techniques/aids need to be developed.
  - Cleaning, especially of the sealing edges.
  - Unequal expansion, leading to cracking and breaking of parts.
  - Incorrect insertion of components – expansion leads to pressures and then the “weakest link” breaks; so that the part that breaks is not necessarily where the problem lies.

- Leak tightness

  This is very important, for ensuring no air leaks in and no process gases leak out.

  It is also important that within the coater no gases leak from the coater internals into the coater body.

  - There are dry joints between the graphite parts. It is very important that careful inspection is applied here – there must be no rattle fits. It is especially difficult to set the correct tolerances for all parts together.
  - Joint between gas lance and internals – it is very difficult to ensure that the seal is good during assembly and insertion of the internals into the coater

  Leakage leads to:

  - Poor coatings, as not all the gas is used for coating. This is shown by reduced layer thicknesses.
  - Poor temperature and pressure control due to carbon depositing where it is not required.
  - Soot deposition elsewhere, causing short circuits or poor heating due to wrong paths being followed by the electrical current.
  - Partial short circuits putting undue strain on the delicate electronic components of the systems.

- Gas Flows

  Ensuring that all gases flow optimally in all layers is very tricky.

  - Certain gases flow at different rates at different times – flexibility is essential
  - As the layers are deposited – the bed resistance increases, giving more back pressure. Also the holes in the gas distributor start to close up, also increasing the back pressure. This means that the gas flow control needs to be able to compensate for varying back pressures from the coater.

- Cleaning and Soot

  - The soot produced in such a coating process is very fine and penetrates everywhere, especially all the undesirable places.
  - Cleaning must be optimised, otherwise it takes an exorbitant amount of time.
  - Soot is an extreme respiratory irritant, even though it is intrinsically non-toxic. There is a need to take great care when cleaning the coater, the systems and the parts for the coater.
  - We found it best to do all cleaning of parts in enclosed areas, especially in a “glove box”, where contact with personnel is minimised by the use of gloves etc.

CONCLUSIONS

All **goals** of the **1 kg coater** have been achieved

- Enhanced understanding of the process and of coater design, especially because the coater had to be modified to bring it into the correct operation regime.
- Regular operation of the coater has meant that there is regular training for the associated personnel.
- Material for the Quality Control and Fuel Sphere laboratories has been provided on a regular basis.

Cold commissioning of the **5 kg Coater** is in its final stages with the use of process gases, heat and simulation kernels and all is proceeding well.

The coater itself is **equivalent** to the German design and works very well. The ancillary systems, which are different to the German systems, are those that have given most teething problems during commissioning.

The next step will be “hot” commissioning, which is due to commence in October 2006, when UO_2 kernels (already manufactured by the Kernel laboratory) can be introduced into the coater.

ACKNOWLEDGEMENTS

Thanks are due to:

- Dr P Crouse for his scientific knowledge, for push starting the whole 1 kg coater project, and for getting it off the ground.
- DJ Booysen for his project management of the 1 kg coater and for the operation of the coaters.
- JP le Grange for all his work on the PLC and SCADA systems.
- Other far-sighted people who supported the projects.
- Necsa for the use of laboratories and management services.
- PBMR for support (moral, resources (many PBMR personnel)) and especially management of the 5 kg coater project.
- Especially all the current coater personnel
  D J Booysen
  S M Dlamini

J F du Plessis
J J Hancke
M T Mutshena
D I Venter
J Vosloo

Without these people, it would not have been possible to have reached the position we are in today.