# REFURBISHMENT OF THE PLASMATRON VISION I FOR PLASMA WALL INTERACTION STUDIES AT SCK•CEN WITH DEUTERIUM/TRITIUM PLASMA

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## ABSTRACT

Plasma facing materials (W, Be, CFC) for future fusion reactors (ITER/DEMO) have to meet many requirements. The properties of these materials when exposed to a deuterium/tritium plasma are likely to be as important in determining their applicability. Therefore, it is necessary to have facilities and analysis laboratories that are able to investigate material properties such as T recycling/retention, dust production, resilience to large steady state fluences, surface erosion and material redeposition of plasma facing materials. This paper describes the refurbishment of the plasmatron VISION I. An important facility to address some of the key issues in plasma wall interaction as it will be able to work with tritium, beryllium and on neutron irradiated materials, under high flux densities and low ion plasma temperatures. The refurbishment is expected to be completed by the end of 2010. The vacuum system is already back in operation. The generation of the first plasma (Helium) is scheduled for December 2008.

- Keywords: Fusion, plasma facing materials, tritium retention

## Introduction

The plasmatron facility has been recovered from the EC-JRC Ispra site, from the ETHEL (European Tritium Handling and Experimental Laboratory) [1] building, which is decommissioned and for which the installations and facilities situated inside have to be dismantled or evacuated. After the necessary arrangements between SCK•CEN and the JRC Ispra, the facility was transferred to Mol in the year 2007.

After a thorough literature study, discussions with specialists and participation in the working groups around plasma-wall interaction studies, the purpose and objectives of the plasmatron could be more precisely defined. There is a strong need for experiments including tritium gas, Beryllium and irradiated materials (tungsten, steel, carbon, mirrors). Regarding the experience in the nuclear field present at the SCK•CEN (as well as on tritium and Beryllium handling, as on the manipulation of irradiated materials), it was decided to refurbish the plasmatron in this direction. This would make the plasmatron VISION I (Versatile Instrument for the Study of ION Interaction) a unique facility in the world for testing plasma facing materials, including Beryllium and irradiated samples, exposed to a tritium containing plasma.

This paper will give shortly the field of application of the plasmatron VISION I, the operation of the ion source, the planning for the coming years and finally the current status of the refurbishment.

## Field of application

Plasma facing materials for ITER and DEMO have to meet many requirements already considered in the R&D programme (fabrication feasibility, resilience to neutron damage and activation, etc.). However, other aspects concerning the behaviour of the materials under exposure to plasma in ITER- and DEMO-like conditions are likely to be as important as those above in determining their performance/use (namely : T-retention, dust production, resilience to large steady-fluences & transient loads, surface erosion and material redeposition) and should be addressed [2].
The key plasma facing material issues [3] are determined by synergistic effects of plasma steady-state flux, transient fluxes and material damage by neutrons. Therefore, it

is necessary to have facilities and analysis laboratories that are able to investigate these synergistic effects. The plasmatron VISION I that will be operated at SCK•CEN will have the ability to work on some of the key issues in plasma wall interaction (PWI) as it will be able to work with tritium, beryllium and on neutron irradiated materials, under high flux densities and low plasma temperatures.
The Plasmatron VISION I provides the capability to investigate PWI phenomena such as steady-state erosion, ageing, deposition, alloy mixing, recycling, implantation, diffusion, retention, … as a function of material grade, surface temperature, plasma parameters, plasma gases (deuterium, tritium, seeding gases, …).
Key issues:

- influence of long pulse operations on PFM
- Be/T and neutron irradiated materials
- mirrors/windows, diagnostic studies (erosion/redeposition/dust) and cleaning methods
- erosion/redeposition (dust) studies
- tritium retention/inventory/trapping/implantation/aging/…
- tritium/codeposited (dust) in-situ removal methods (glow discharges, …)

From Table 1 it is clear that none of the available plasma simulators are capable to simulate fully the ITER conditions. Magnum-PSI and Pilot-PSI (Netherlands) are the only two facilities that are and will be able to simulate the very high dense plasma. Presently only one facility is capable of operating with beryllium materials and this is PISCES-B in the US. However, none of the existing plasma simulators can operate with tritium and/or activated materials. Therefore the plasmatron VISION I will be unique in its kind.

| | PISCES-B | Magnum-PSI | Pilot-PSI | NAGDIS-II | PSI-2 | Plasmatron VISION I | ITER |
|---|---|---|---|---|---|---|---|
| **$n_e$ ($m^{-3}$)** | $10^{17}$-$10^{19}$ | $10^{19}$ - $10^{21}$ | $10^{19}$-$10^{21}$ | $<10^{20}$ | $10^{17}$-$10^{20}$ | NO DATA YET | **$10^{19}$-$10^{22}$** |
| **$T_e$ (eV)** | ~4-40 | ~0-10 | ~0-7 | ~5-10 | ~1-20 | NO DATA YET | **Div: ~3 MidP:~100** |
| **$T_{ion}$ (eV)** | 0.1-0.5 $T_e$ | ~$T_e$ | ~$T_e$ | 1-10 | 0.5-0.6 $T_e$ | 20-500 | **Div: ~15 MidP: ~500** |
| **σ ($m^{-2}$ $s^{-1}$)** | $10^{19}$-$10^{23}$ | $10^{23}$-$10^{25}$ | $<2.10^{25}$ | $<10^{23}$ | $10^{22}$-$10^{23}$ | $10^{20}$-$10^{21}$ | **$10^{24}$-$10^{25}$** |
| **τ (s)** | Steady state | Steady state | 3-10s | Steady state | Steady state | Steady state | **300-500s - steady state** |
| **Preheat Target** | Plasma heating | Plasma heating | Plasma heating | Room temp. | Room temp. | 20-600 °C | **Bake temp. < 230 °C** |
| **$P_n$ (Pa)** | 5 $10^{-4}$-$10^{-2}$ | ~1 | ~1-10 | ~0.1-4 | 0.01 | 0.05 – 0.5 | **1-10** |
| **B (T)** | 0.015-0.05 | <3 | 0.4 - 1.6 | <0.25 | 0.1 | 0.2 | **5.3** |
| **Target material** | C, W, Be, metals, mixed | C, W, metals | C, W, metals | C, W, metals | C, W, metals | C, W, Be, metals, mixed | **C, W, Be, mixed** |
| **Be** | Yes | No | No | No | No | Yes | **Yes** |
| **T** | No | No | No | No | No | Yes | **Yes** |
| **Nuclear** | No | No | No | No | No | Yes | **Yes** |

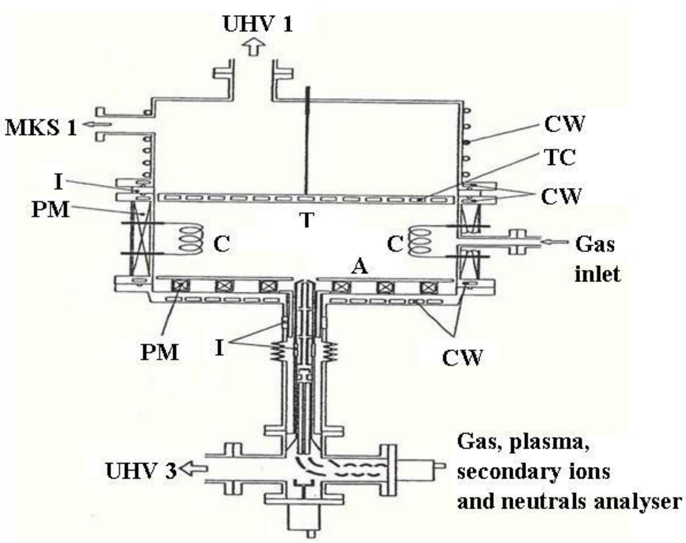
$n_e$ = electron density/ $T_e$ = electron temperature/ $T_{ion}$ = ion temperature/ σ = Ion flux density/ τ = pulse length/ $P_n$ = neutral gas pressure/ B = magnetic field/ Div = detached divertor area / MidP = midplane

**Table 1: Comparison of various plasma parameters from high fluence, low ion temperature plasma simulators versus ITER**

## Operation ion source

The plasmatron VISION I is an experimental device to investigate issues related to PWI and material properties under steady state heat and particle fluxes and low ion plasma temperatures. The core of the plasmatron is the measurement chamber, which is a cylindrical vessel of approximately 400 mm height, 290 and 250 mm, outer and inner diameters, respectively (Fig. 1).
The bottom part, which is electrically insulated from the rest of the cylinder by an Al2O3 ring, constitutes the anode of the multipole ion source which acts as plasma simulator. A multipolar magnetic field is produced by strong Samarium-Cobalt (Sm2Co17) permanent magnets mounted on the anode outer surface; field intensity is about 0.2 Tesla at the

inner surface and is rapidly decreasing with distance from the walls, so that the inside of the ion source can be considered field-free.
Plasma production is accomplished by electron bombardment in a low-pressure fill gas (DT mixture). Electrons are produced by two 1 mm tungsten filaments (cathodes) located in the field free region and ohmically heated up to 2500K. Ionization takes place when a discharge potential between the cathodes and the anode is switched on. The probability of ionization is augmented by the magnetic field, which increases the electron mean free path (helical trajectory).
In order to extract the heat produced by the electron load, which is able of inducing anomalous out gassing signals, the anode is water-cooled. Ion bombardment is started when the discharge potential is established; ion energy is regulated in the range 20 – 500 eV by a DC power supply between the anode and the target. The ion current is driven by electronic emission intensity; since the probability of ionization (and consequently the number of ions) at a given pressure is a function of the electrons emitted from the cathodes. In order to sustain the desired ion flux, the temperature of the cathode is controlled by adjusting the power to the filaments.




| | |
|---|---|
| UHV1 | main pumping |
| MKS | capacitance manometer |
| CW | cooling water |
| TC | temperature control |
| I | insulation |
| PM | magnets |
| T | target |
| C | cathode |
| A | anode |
| UHV3 | differential pumping |

**Fig 1: Schematic view of the ion source**

Ion current density ranges from 5 to approximately 100 A.m-2. Equivalent with an atomic flux density of 1x1020 to 2x1021 atoms.m-2.s-1 at the target (pressure P = 0.3 Pa). In the target, 240 mm diameter and 24 mm thickness, a spiral path has been carved inside the disc for the circulation of the temperature conditioning fluid. Four thermocouples penetrating about 0.5 mm from the front of the target surface are placed at different radial positions. The target is held in position by three water-cooled copper holders.
The experimental chamber will be equiped with a high sensitive quadrupole mass/ion energy analyser. Allowing the measurement of not only the gas composition but also the detection of the secondary flux of particles ejected from the target during the ion bombardment.

To be tritium compatible, the plasmatron has been designed with oil-free pumps. Depending on the tritium level, two modes of operation are distinguished. In the low-level mode gas is removed by a magnetic bearings turbo molecular pump backed by a combination of a molecular drag and a membrane pump in series. Once the chamber has reached UHV conditions (i.e. p ~ 10-6 Pa), the system can be switched to the high-level mode, in which tritium storage and removal is accomplished by two regenerable bulk getter pumps. These pumps are also effective in adsorbing impurities (N2, O2, H2O, CO, …) irreversible, while hydrogen isotopes are pumped reversibly. [4] [5]

## Planning

The major deadlines of the refurbishment and commissioning of the plasmatron VISION I facility are given in Table 2.

| | |
|---|---|
| June 2008 | Vacuum system back in operation |
| Dec 2008 | First Plasma (Helium) |
| June 2009 | Installation Diagnostics (QMS) |
| | Development of control and visualization software |
| Dec 2009 | Installation of the plasmatron in a glove box |
| | First scientific experiments with deuterium plasma |
| Dec 2010 | Beryllium, tritium, low-activated specimens licensed |

**Table 2: Roadmap refurbishment and commissioning of the plasmatron**

## The Refurbishment

For 2008, two milestones were set. To have the vacuum system back in operation and to generate the first plasma.

## Vacuum System

After transportation of the glove boxes to our work area, the plasmatron was carefully dismantled. As the plasmatron was inoperative for nearly 15 years and transportation damage could not be excluded, the correct operation of each component was checked. Defective or missing parts were replaced. The capacitive manometers were send to the manufacturer for calibration. The pneumatic gate valves were found to be in a very good condition and will be as-new after a general maintenance procedure.
After thorough cleaning, the vacuum system was reinstalled on the new frame (Fig. 2). The plasmatron will be installed in the glove boxes after complete refurbishment. A Helium-leak test was performed and after one week of pumping, a pressure of 5x10-7 mbar was reached in the plasma chamber. Isolating the plasma chamber from the rest of the system resulted in an increase of the chamber pressure to 6x10-5 mbar (after 24 hours). Indicating still a significant portion of out gassing. As the vacuum system was exposed to the atmosphere for a very long time and no bake-out was performed, the obtained pressure of 5x10-7 mbar is considered excellent. As the ultimate pressure can still be improved by taking proper actions, it is concluded that the first vacuum was successfully reached on the 11th of July 2008.

## First Plasma

The generation of the plasma requires a significant portion of automation and control. As the majority of the original instrumentation and control equipment disappeared over time or became outdated, a new control cabinet has to be designed and constructed. This involves: 1) the selection and purchase of new equipment such as PLCs, switch gear, power supplies (filaments, gas ignition, target potential), getter pump controllers, target temperature controller, etc., 2) the drafting of electric circuit diagrams and the cabinet layout, and 3) the writing of control software for the PLCs. A new cooling system for the plasma chamber (de-mineralized water) also has to be build. The generation of the first plasma is intended to demonstrate the functionality of the new instrumentation and control equipment. Initially an inert gas (Helium) will be used for safety reasons.
The construction of the new control cabinet is nearly completed (Fig. 2). The software development for the PLCs and the control of the power supplies for the plasma generation are in progress. The generation of the first plasma by the end of 2008 is still considered feasible.

**Fig 2: Vacuum system installed on the new frame (left) – New control cabinet (right)**

## Conclusion

The plasmatron VISION I that will be operated at SCK•CEN will have the ability to work on some of the key issues in plasma wall interaction since it can work with tritium, Beryllium and on neutron irradiated materials, under high flux densities and low ion plasma temperatures. The full refurbishment and commissioning is scheduled to be completed by the end of 2010. The vacuum system is already back in operation. The generation of the first plasma (Helium) is foreseen for December 2008.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ABSTRACT

Characterisation of sludge and liquors within the legacy ponds at Sellafield is a critical step in underpinning the waste treatment processes. The National Nuclear Laboratory (NNL) has designed, manufactured and tested equipment which has allowed two separate groundbreaking sampling campaigns in these ponds. To allow informed design decisions on proposed downstream plants, knowledge of sludge settling behaviour and aspects of activity transfer to liquor.

This novel, in-situ pond technique utilises a cylindrical upturned vessel that contains equipment designed to measure sludge settling rates and activity transfer from the disturbed sludge. This equipment worked very successfully and results were used to inform the design of downstream plant tankage and effluent treatment.

Building on this success, a more ambitious project was undertaken to take samples of sludge from the First Generation Magnox Storage Pond as well as samples of liquor and sludge suspended through agitation. To ensure successful deployment, the equipment was comprehensively tested at the NNL Workington Laboratory.

## 1. Introduction

Characterisation of sludge and liquors within the legacy ponds at Sellafield is a critical step in underpinning of the design and engineering of its waste treatment processes. Previously, this characterisation work has been achieved by extracting discreet samples. In many instances the high active nature has limited the size, number of the samples and confined much of the characterisation work to hot cell operations. Subsequent analysis of these samples has demonstrated that the wastes are very heterogeneous. The small volumes have also made it difficult to measure physical parameters, such as settling rates that could be reliably related to plant operations. Furthermore, the action of sampling can denature the sample and destroy some of the properties requiring measurement, for example, the rheology or the amount of activity released from the sludge on disturbance. To overcome these difficulties, an alternative strategy was required, i.e. perform the characterisation experiments in the radioactive plant environment (in-situ). As part of this initiative The National Nuclear Laboratory (NNL) designed and developed two 'bell jars' for the in-situ examination of sludge settling characteristics and activity release from sludges.

In simplistic terms a bell jar is an inverted, open, vessel that is lowered into the pond sludge bed. The vessel isolates a few litres of liquor and sludge and incorporates a mechanism for agitating the trapped sludge. The effect of the sludge mobilisation upon the trapped liquor is then monitored by extracting a series of liquor samples versus time. Other monitoring equipment may also be fitted.

Although it is considered harder to control all the parameters of interest with in-situ experiments they offer several advantages over the use of small ex-situ sludge samples:

- In-situ experiments allow much greater quantities of sludge to be used in the experiment and therefore the results are less susceptible to sludge heterogeneity.
- In earlier studies a simulated liquor had to be added to the ex-situ sludge samples.
- Less active liquor samples are required for analysis, thus dose uptake is reduced.

Undisturbed sludge may be isolated, whereas the action of taking a sludge sample for ex-situ analysis can result in some disturbance and loss of some entrained activity.

To support sludge retrieval operations from the Pile Fuel Storage Pond, the first 'bell jar' was designed to address the sludge settling rate and activity transfer during retrieval operations.

These issues are particularly important for retrieval operations as the settling characteristics impact upon tankage provision and liquor return times, and the extent of activity transfer from disturbed sludge to liquor impacts upon the pond water activity and dose uptake to operators. The second bell jar was designed to assess the extent of activity transfer from disturbed sludge to motive liquor during hydraulic transfer of sludge in support of retrieval operations from the First Generation Magnox Storage Pond.

## 2. Pile Fuel Storage Pond Bell Jar

The Pile Fuel Storage Pond Bell Jar consisted of an inverted chamber that isolated a portion of pond sludge and liquor and was deployed on the end of a pole via the pond crane. The sludge was mobilised via a submersible pump that re-circulated the liquor and sludge through a sparge ring fitted at base of the unit. The bell jar was equipped with instruments that would allow the subsequent settling rate to be determined. For continuous clearing, a turbidity meter and visual clarity markers were monitored with a camera through a window. A falling interface was monitored against a vertical scale alongside the window using a camera. A schematic and photograph of the bell jar are shown in Figure 1.

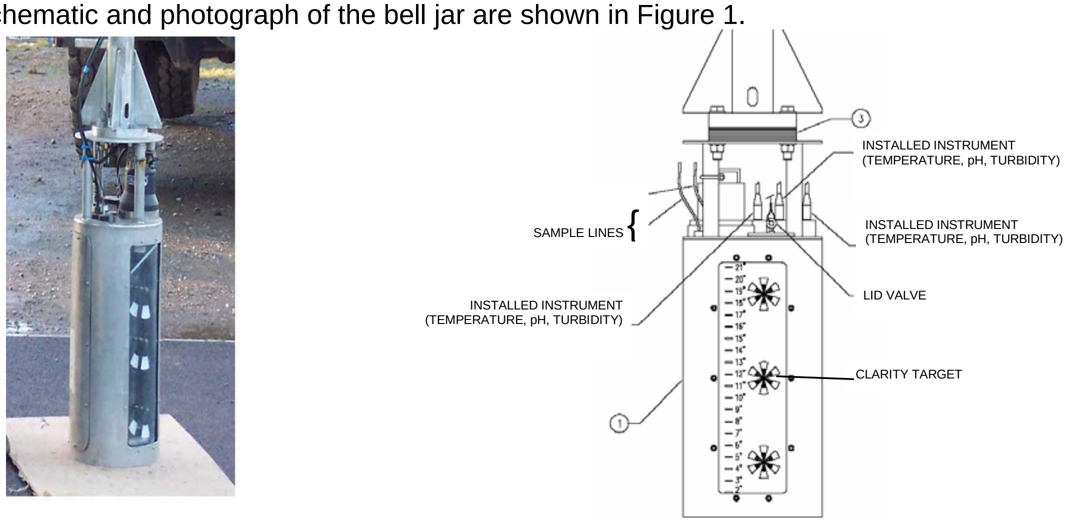


**Figure 2: Bell Jar used in Pile Fuel Storage Pond**

### 2.1 Settling Characteristics

To monitor the settling rate, the solids concentration was measured by monitoring the liquor turbidity and clarity. Turbidity was logged continuously and the clarity was measured by way of three series of visual targets mounted horizontally through the liquor at three fixed heights (see Figure 1). The targets were arranged as spirals with 12 segments set as clock positions, each offset one inch further back from the window. Thus, the clarity of the liquor could be monitored by noting how many of the target segments were visible.

(a). (b).

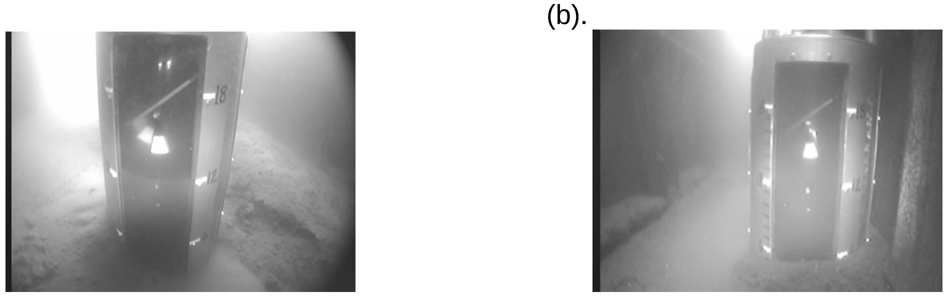

**Figure 3: Example video captures showing (a) a distinct interface (close to marker 12) and (b) a clearing fog.**

As a result of the settling trials, two modes of settling were observed: either a distinct falling interface with clear liquor above, or a clearing fog. Examples of these settling modes are given in Figures 2a and 2b.

From these trials, our customer, the Sellafield Ltd Waste Retrieval Project was able to quantify settling rates and conclude both settling modes exist in Pile Fuel Storage Pond and the material settled to its original volume.

## 2.2 Activity Release from Disturbed Sludges

Sludge that has been left undisturbed for prolonged periods, the activity builds up in trapped sludge pore liquor either from leaching and/or ongoing corrosion. When the sludge is disturbed this pore liquor, and its associated activity, is released into the surrounding liquor. There are significant uncertainties in quantifying the generation rate of this activity in the pore liquor and the amount that would be released into the process liquor during retrieval operations. It is important that this activity release behaviour is understood so that the challenge to downstream effluent treatment plants can be estimated and that the appropriate activity abatement technology can be installed. In the case of the Sellafield site, ion exchange abatement technology is used and it is particularly important that the release behaviour of Sr-90 and Cs-137 is understood as their removal is hindered by Group 1 and 2 metal competitor ions such as sodium, potassium, calcium and magnesium.

The activity of the liquor trapped in the bell jar was assessed by taking a baseline liquor sample before any sludge disturbance and taking samples following a fixed disturbance versus time. In contrast to previous observations made on ex-situ samples taken from alkaline dosed ponds, the Sr-90 activity in the liquor decreased slightly after mixing and settling the sludge. It is thought that the decrease may be the result of some component of the sludge acting as a mild ion-exchange medium and active suspended solids being removed from the liquor by flocculation of particles during the settling process.

## 3. First Generation Magnox Storage Pond Bell Jar

To enhance the limited active data available for the sludges stored in the First Generation Magnox Storage, the NNL developed a second bell jar to understand the amount of activity that would be released from disturbed sludge. Without this it is very difficult to assess the anticipated activity challenge to down-stream effluent treatment plants.

As with the waste stored in Pile Fuel Storage Pond, the sludge in the First Generation Magnox Storage pond is heterogeneous and an unquantifiable amount of the activity associated with the sludge pore liquor could be lost during ex-situ sampling. The NNL proposed to address this issue by designing a second bell jar. However, there were a number of design criteria that needed to be considered in transferring the use of this technology to the First Generation Magnox Storage pond:

1) The driver for this work was to assess activity release from disturbed sludge to the bulk liquor during skip movements and retrieval operations.
2) The number of potential locations for the bell jar deployment would be limited as the First Generation Magnox Storage Pond contains many more closely packed skips.
3) The water sparge ring used in the Pile Fuel Storage Pond bell jar to mobilise the sludge would be insufficient to disturb the denser pond sludge.
4) Suction from the sludge may build up making it difficult to retrieve the bell jar from the sludge bed after deployment.
5) It would be necessary to determine the amount of sludge disturbed.
6) The background dose rates to operators would be much higher than before.

A prototype version was manufactured to demonstrate the principles of operation and this progressed through to full deployment trials with the full bell jar at the NNL Workington Laboratory.

In summary the design philosophy was based on the following principles:

1) The sludge would be mobilised by use of a more powerful submersible motor and rotor.
2) It would be fitted with cameras to monitor its descent and allow operators to deploy the system without looking over the wall, thus reducing dose uptake.
3) It would be fitted with four passive syringe type samplers to extract small sludge samples.
4) The bell jar would have a sludge depth gauge system monitored via fitted cameras.
5) Water pumped through small jets around the base plate would ease bell jar retrieval.
6) A flange would be fitted around the bell jar to support the four sludge samplers.

### *3.1 Inactive Concept Trials*

To develop the design further it was important to determine whether the key concepts for the design were feasible. Therefore, using simplified prototypes of the bell jar and sludge sampler, the following were investigated.

- Bell jar penetration.
- Sludge mobilisation
- Amount of sludge disturbed.
- Sludge sampling.

### 3.2 Bell Jar Penetration

The earlier bell jar (Figure 3) was deployed via the skip handler and, if necessary, the bell jar could be twisted into the sludge using the cross bars at the top of the deployment mast. However, in the case of this new design, it would have to sink into the sludge under its own weight. The rheology of the sludge in First Generation Magnox Storage Pond was uncertain due to the limited physical characterisation data available. However, it is known that the sludge is largely the result of the corrosion of Magnox fuel cans and residual fuel. Over the years the NNL have worked on a number of full-scale, inactive development trials for the retrieval of these wastes and has built up considerable experience in the design and use of legacy pond simulants. Therefore, using this experience, two Magnox sludge simulants were selected to represent a hard and soft challenge. In the weaker simulant (5kPa) the bell jar penetrated immediately to the required depth. The thicker simulant (18kPa) had a hard crust on the surface 1cm thick which it penetrated with additional weights.

A pond survey was performed for the first location to ensure that these were clear of miscellaneous items that could foul the deployment. The camera was fitted with a metal rule that could sink into the sludge so that simple rheology tests could be performed. For the first location, the rule sank readily into the sludge and the area was visibly clear.

**Figure 3: Pile Fuel Storage Pond bell jar and deployment mast.**

### 3.3 Sludge Mobilisation

Unlike the first bell jar, a more powerful system would be required to mobilise the denser sludge (typically 1.6-2.5gcm$^{-1}$) found in the First Generation Magnox Storage Pond. Therefore in this design a rotor powered by a more powerful submersible pump was trialled. The rotor readily mobilised all simulants tested.

### 3.4 Amount of Sludge Disturbed

So that quantitative measurements for the release of activity from the sludge to the liquor phase could be made, it was important that both the volume of sludge and liquor disturbed were known.

In the first bell jar the sludge was mobilised from the base and therefore, by monitoring the height of the sludge through the window it was relatively easy to calculate the volume of sludge disturbed. The liquor volume could then be calculated from the internal dimensions. However, in this second design, the sludge had to be mobilised from above and therefore it was rather more difficult to assess how far the effects of the rotor had penetrated through the sludge.

**Figure 4: Redesigned 'mesh' depth gauges.**

Therefore in the First Generation Magnox Storage Pond bell jar design, it was proposed that the amount of sludge disturbed would be determined by monitoring a depth gauge rod that would sink into the sludge as it was disturbed. The top portion of the depth gauge rod was designed to penetrate through the top of the mixing chamber so that the sludge depth could be monitored via the onboard cameras. In the thin simulant (5kPa) the depth gauge sank immediately through the sludge. However, addition of a flat plate to the base of the depth gauge significantly increased its resistance to sinking through the simulant. The flat plate was replaced with a 'mesh' design to reduce the weight of the depth gauge and to expose the solids beneath the 'mesh' plate (see Figure 4).

### 3.5 Sludge Sampler Design

The design intent was that four sludge samplers would be fitted around the periphery of the bell jar (see later) and these would sink into the sludge bed as the bell jar sank into the sludge under its own weight. The sludge sampler was essentially an open, shielded, tube that relied upon the self adhesive properties of the sludge and a rubber 'sphincter' at its base to retain the sample. The sludge sampler was effective and retained the thin simulants trialled. These trials indicated that the chamfer of the base of sludge sampler needed to be sharper so that it would sink more easily into the sludge.

### ***3.6 Final Design***

Following the above, successful, prototype trials the design was modified accordingly and the revised design bell jar was manufactured (Figure 5). The submersible motor mounted on the exterior above the mixing chamber with an impeller attached to the inside. The bottom edge of the bell jar was chamfered to assist with insertion into the sludge. A circular plate mounted on the exterior of the bell jar to limit the depth of submergence into the sludge and support the four sludge samplers. An external ring of water jets were fitted on the underside of the circular plate to mobilise the sludge on the outside of the bell jar to reduce any suction that may have built up whilst it was on the sludge bed and ease bell jar retrieval. Three cameras were fitted to monitor the 'depth sticks' to indicate the level of sludge disturbed inside. Two liquor sample tubes were also fitted. Liquor samples were extracted from inside the bell jar via a hand operated vacuum pump. The sludge samplers are secured in place on the bell jar flat circular plate by a quick release cam lever, thus enabling quick and easy manual removal of active samples.

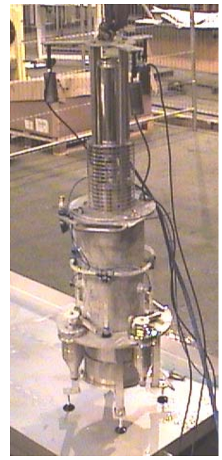

**Figure 5: Bell jar final**

### 3.7 Deployment Trials

Full deployment trials were performed at the NNL Workington Laboratory. This facility has a rig hall space of 8000$m^2$ and craneage hook to lift 60 tonnes up to 8m. For these trials the 6m deep pit was used to mimic the pond conditions. The lifting beam and hoist that would be used on plant were also replicated. Figure 6 shows the bell jar being deployed into the pit. These rigorous deployment trials offered the opportunity to develop the deployment methodology, train operators and demonstrate its deployment in a safe environment.
During the course of these trials we were able to define:

- the work platform layout and where operators needed to be to minimise dose uptake.
- additional items of kit that would be needed to ease washing and handling of the bell jar and its 15m umbilical cable.
- methodologies for bagging the equipment to minimise spread of contamination.

**Figure 6: Bell Jar deployed in the 6m deep pit.**

### 3.8 Plant Trials

At the time of writing this paper all inactive trials had been completed and the bell jar had been delivered to the First Generation Magnox Storage Pond and the project is now moving into the deployment phase.

### 4 Conclusion

By having a thorough understanding of the characterisation needs of our customer, the NNL has been able to devise an innovative solution. The bell jar sampling methodology developed by the NNL offers many advantages over extracting small discreet samples and will provide the customer with significantly more useful data.

To date the bell jar methodology has allowed one retrieval project to assess its operational sludge settling times, tankage requirements and downstream effluent treatment requirements based upon the activity release and settling measurements made. This is key information in Sellafield Ltd.'s rigorous underpinning of the design of the waste treatment processes.

The technology has been successfully modified for deployment in a rather more challenging environment. The NNL has been able to use the same philosophy but to adapt it to measure different characteristics depending upon the customers challenge.

Finally, undertaking trialling at the NNL Workington Laboratory has been key in developing the design, deployment methodology and training operators.

## 5 Acknowledgements

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