

PREPARING AN INERTED STORAGE SILO FOR DECOMMISSIONING

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The decommissioning of redundant plant at Sellafield is proceeding as a priority. One of the major activities is to remove metallic and organic radioactive wastes from a large reinforced concrete storage Silo. As an initial step, the Silo was inerted with argon gas 4 years ago. Since then substantial operations have taken place on the Silo to prepare for retrieval. These include removal of redundant plant and equipment, strengthening of plant to take account of modern standards, and drilling into the Silo to allow access to the waste.

The paper describes the experience learnt in carrying out these operations, and in managing maintenance of the inert gas atmosphere, whilst minimising asphyxiation risks.

Inerting is commonly thought of as the 'gold standard' of fire hazard management, and is being considered for several retrieval plants. Designers and Regulators need to be aware of the positive and negative aspects in order to reach a balanced decision regarding use of inert gas.

KEYWORDS: ignition, inert, gas, oxygen, flammability, argon, silo

INTRODUCTION

There are several Intermediate Level Waste (ILW) stores located on the Sellafield site. One of the major activities at the Site is to remove metallic and organic wastes stored in air in one of these stores, a large concrete Silo. One of the significant preparatory tasks was to inert the Silo with argon in 2001, experience of which was reported at HAZARDS XVII[(1)]. Since then, significant structural alterations continue to take place whilst the inert gas cover has been maintained. These are being undertaken in advance of waste retrieval operations that will require the construction of new facilities at a cost of >£100M.

The silo was built just after World War II at the start of the Cold War to provide waste storage facilities for the cladding from spent nuclear fuel initially arising from the military programme and later from the early civil nuclear programme. Radioactive wastes were loaded and stored inside the silo within an air atmosphere.

This paper highlights the experience gained over the past 4 years maintaining argon in within the structure, which was not designed to retain inert gas. Some of these lessons will be relevant when considering application of inert gas to other old structures.

PLANT DESCRIPTION

The Silo and its associated plant and equipment is a permanent concrete structure located within the separation area at Sellafield in a congested area, surrounded by many buildings, pipebridges and other structures. It was designed and constructed in the late 1940s and early 1950s. It consists of a reinforced concrete structure divided into several compartments containing intermediate level waste (ILW). A transfer tunnel ran along the Silo roof, which was used for tipping operations. This transfer tunnel was isolated from the Silo compartments using 2te plugs fitted into each compartment chargehole, and it was removed in 2004 by hands on demolition.

The waste is made up of several materials, principally magnesium alloys, aluminium and graphite, which arose principally from the decanning of pile fuel and early magnox operations. Evaluation of the hazards in the materials led to the decision to provide an inerting system to keep the oxygen concentration below the limits of combustion of 4% O_2 in argon. Prior to introduction of argon, significant sealing works took place including coating the whole of the concrete external surface of the Silo with a nominal 1 mm layer of sealant. Argon is provided to the compartments from two storage and vaporisation plants (System A). It is designed to be very reliable with a degree of redundancy. Also, an argon fire fighting system has been provided. A second argon system (B) is being installed to give diversity of supply of argon through a fully seismically qualified system which will inject argon through the top of the Silo.

The current System A inerting flow is introduced through drainage connections at the base of the Silo. An engineered ventilation system is used to purge any oxygen which controls the pressure in the Silo to nominal depression (-10 to -50 Pa). This is to minimise the flow of air into the compartments and also, any flow of contaminated argon into the environment (a large flow of air into the compartment, due to high depression, would increase the oxygen concentration and would compromise inerting, while a significant positive pressure could lead to a loss of argon from the Silo which could spread contamination). Water filled lutes protect the Silo against over or under pressure.

The project strategy has been to carry out operations and building improvements which would reduce the overall risk presented by the waste and the building. Argon inerting is a key part of this and several activities have been directed at improvements to the Silo building and structure which allow better retention of the argon in the Silo. These are discussed below.

BEHAVIOUR OF ARGON DURING COMMISSIONING

The commissioning work, as discussed in [1], showed that the argon filled the compartments as if it were flooding the compartments, akin to filling a bath. This implied that there were no significant areas of high oxygen concentration remaining within the bulk of the waste. The gas behaviour gave confidence that gas sampling, which could only be carried out at the top of the compartments, was representative of bulk conditions. Also, the behaviour confirmed that the estimates of voidage made during experimental trials were consistent with the actual waste voidage.

BEHAVIOUR OF ARGON POST COMMISSIONING

INTERNAL TO SILO

A pattern emerged in the oxygen concentrations in the Silo, once the commissioning of the argon had been completed. The concentration of oxygen fell at the top of the compartments and stayed well under 1% for a considerable amount of time. The oxygen concentration at the bottom of the tunnel was also under 1% for the majority of the time. The oxygen sample points at the midpoint of the tunnel registered in the range 1 to 2% showing some variations in this range but staying below 2% for the majority of the time. At the roof level of the tunnel the oxygen concentration rarely fell below 2% and show wide variations between approximately 10% and 2% (Figure 1). A variation in the oxygen concentrations along the tunnel was also seen with the oxygen concentrations being higher at the compartment 1 end from the compartment 6 end.

It was concluded that the behaviour seen was due to two separate mechanisms. The first was the buoyancy effects of the oxygen naturally moving towards the highest point due to the density differences of argon and oxygen. Secondly it was thought that the tunnel was the leakiest part of the Silo, with a strong suspicion that the joint between the walls of the tunnel and the roof being the most significant source of leakage, because the top of the tunnel was at the most significant depression relative to atmospheric. The pressure at the top of the tunnel was controlled by the ventilation system in the range -10 to -50 Pa. Due to the differing density of air and argon the differential pressure across the wall to atmosphere changed until part way down the compartment the pressure difference became positive. As there is very little potential for the out leakage of argon lower down the compartments due to the building construction this was deemed to be satisfactory.

The variation along the tunnel was attributed to leakage at the door from the tunnel to the ante chamber. This door was replaced with a specially designed door to stop both the air entering the tunnel and also the argon leaking out into the antechamber as it was required to have man entry into the ante chamber for future tasks.

As the oxygen concentration at the mid point of the tunnel was below 2%, the waste, above the chargeholes was always kept inerted as it was below the mid point of the tunnel.

The tunnel in this case was acting as a buffer effectively keeping the oxygen concentration in the compartments low and stopping any variations in the air flows into the Silo being observed in the compartments. Compartment 2 showed the highest oxygen concentrations for the majority of the time and was therefore assumed to be the most leaky. It was assumed that the larger crack surface area in compartment 2 was the principal contributor. Compartments 1 and 3 also showed higher oxygen concentrations than the remaining compartments. It was not easy to detect these leaks at the time because of the leakage through the structure of the tunnel. Also it was not possible to pull a vacuum on the Silos due to the leakage rate into the tunnel. This was one of the reasons why tunnel isolation was progressed as rapidly as possible, as it was believed that once the tunnel had been isolated, the leakage rate into the compartments would be much reduced and any compartmental leakage could be identified.

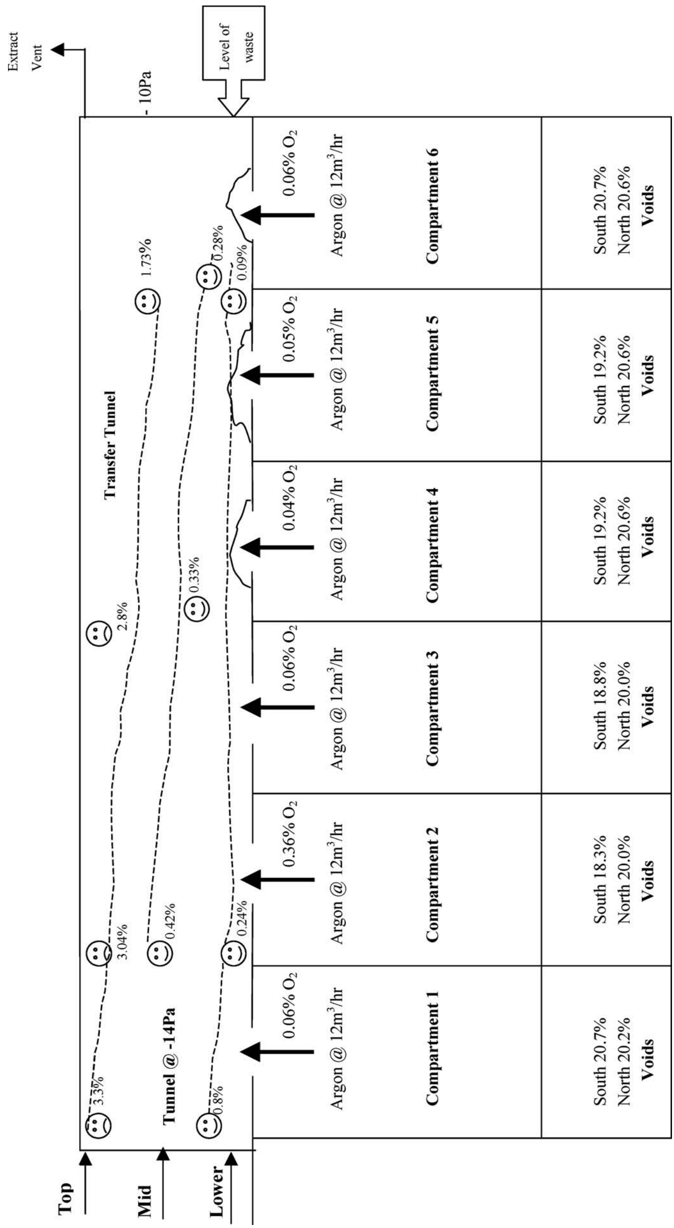

Figure 1. Oxygen concentrations measured during commissioning trials

It was noted that oxygen concentrations continued to vary despite tight control of argon supply and extract, and maintenance of steady pressure. Because the Silo is exposed to the atmosphere near the sea, considerable analysis was done to see if there was a correlation between weather conditions and oxygen concentrations. Some correlation was found with the oxygen concentration rising when the atmospheric pressure was rising and vice versa. Also the wind speed was seen to affect the oxygen concentrations in the compartment as the velocity across the buildings surfaces was thought to induce the flow of gases out of the Silo. However, the correlation was not strong.

EXTERNAL TO THE SILO

A Polyurethane membrane called Copon Hycote 165PW was applied to all the exposed wall areas on the outside of the Silo and the tunnel. This 'Copon' was designed to seal the walls to minimise any leakage through cracks and diffusion through the concrete. Due to the Copon's flexibility, it would cope with differential movement of the Silo. The Copon was tested under laboratory conditions and the results showed that the diffusion rate was reduced by approximately 90%. As the Copon was applied before the Argon inerting was applied to the compartments there is no way to give a definitive value on the reduction in the leak rates due to the Copon, but it is believed to be significant. The Copon and the structure can therefore be said to provide good combination sealant. Hence if trying to inert a similar concrete structure, it would be wise to use a membrane or similar for sealing as many of the surfaces as possible, rather than applying sealant after inerting, and exposing operators to asphyxiation risks.

Argon supply and extract is controlled by conventional systems. If these should fail, water filled lutes protect the Silo against significant over or under pressure. Before the argon was applied the dispersion of argon around the outlet of each water filled lute was modelled using Computational Fluid Dynamics (CFD). This concluded that there was a sphere of radius of 1 m diameter around the lute where there is an argon hazard to operators because of reduced oxygen concentrations. Because the lutes discharge at the top of the Silo, it was possible to exclude the possibility of operators getting close enough to be at risk. The CFD analysis was based on the 'worst case' i.e. highest velocity flows. However, no suitably reliable technique was found to model the escape of argon with little or no pressure drop or driving force from the Silo. This was a concern because there was a requirement to drill holes into the tunnel and Silo roof, which would involve manual operations near the holes. If there was significant outleakage, there would be an asphyxiation risk; a significant inleakage could compromise the oxygen concentration in the Silo.

Calculations indicated that there should be very little inflow of air or outflow of argon if the Silo compartment was effectively kept at atmospheric pressure before the hole was cut and the weather remained stable (wind and atmospheric pressure). Therefore the holes were only drilled when these conditions could be met, and full personal protection was provided. Also, the areas immediately around the holes were carefully monitored for oxygen depletion, as were the oxygen concentrations within the Silo. The actual hole drilling operations were a great success, with no incidents occurring.

A programme of oxygen sampling was carried around the Silo for the twelve months after the start of inerting with particular emphasis on sampling low lying areas around the plant, in case argon was seeping through cracks in the foundations into the ground or underground works. Voids under the Silo were also sampled for the presence of argon. No oxygen depletion has been seen in any of the external areas monitored during the period the monitoring took place. Negligible oxygen depletion was seen in the voids. As a result the monitoring programme has been almost completely curtailed. However, control remains strict:

(i) The Silo is securely fenced with access control
(ii) There are local fixed oxygen depletion monitors with alarms
(iii) Access is controlled to confined spaces
(iv) Additional controls are brought into place if seals have to be broken

Performance of the reinforced concrete structure has been closely monitored throughout the lifetime of the project. Principal techniques at the start of the project were crack width monitors and tilt monitors. 5 years experience has shown no movement despite significant structural changes including removal of the tunnel at the top of the Silo, which was about 10% of the mass of the structure. Maintenance and inspection of these monitors was difficult because of the requirement to provide scaffold access and consequent dose uptake. Therefore, the devices are being replaced with a Leica Precision Monitor. This is situated on a nearby building and will monitor the exact position of the 4 corners of the Silo using a laser prism system.

WASTE CLEARANCE FROM TRANSFER TUNNEL AND CHARGEHOLES

A quantity of waste was present in the transfer tunnel from the late 1950's until 2003. The waste was made up mainly of tangled metal sections which were self supporting and formed effectively a column of waste protruding out of the compartment charge holes into the tunnel. It was necessary to remove this waste to plug the charge holes to achieve the benefits of:

1. Isolation of the compartments from atmosphere. It was expected that isolation would improve the ability of managing the oxygen concentration, as the argon was less likely to be able to leak out adventitously
2. Reduction of radioactive shine from the chargeholes
3. Enabling demolition of the tunnel

Research and development concluded that the waste was locked in place and would require significant energy to lift and place it in other positions. Therefore, a scheme was devised utilising a remotely controlled robotic arm ('Brock') suspended on rails within the tunnel. The Brock was proved to be capable of moving simulated waste. However, the scheme ran into difficulties because it proved difficult to substantiate the performance of the tunnel to take the normal loads and impact loads that the Brock would impose. Significant instrumentation had to be developed to enable a safety case to be made that the tunnel would not be damaged by the Brock. Because of these issues, this element of work was suspended for several years until the Silo had been inerted.

Upon completion of inerting, attention returned to the method of achieving tunnel clearance. Inerting proved that the Silo could be operated with a slight depression, therefore, it could be expected that drilling holes into the Silo would not cause a significant asphyxiation hazard as the argon would disperse quickly if there were small leaks without causing any significant asphyxiation hazard in the open air. Also, it was unlikely that there would be significant flows of air into the Silo. Therefore, a fundamental review of the way forward was undertaken. Two assumptions had led to selection of the Brock:

1. holes should not be drilled into the Silo because of concerns with leakage
2. the waste would require significant energy to move

The first assumption of hole drilling had now been demonstrated not to be a significant concern. Also, it might be true that the second assumption was incorrect and that the waste would be moved more easily, as it had been degrading for 50 years (there was anecdotal evidence from operators that the magnox waste had become brittle and would break up causing the waste to fall into the compartment with very little force). Unfortunately, it was not practicable to representatively sample the waste, and there were concerns about incurring dose uptake without achieving success if the wrong solution was adopted. To find a way forward, it was agreed that a simple design would be developed that involved drilling a hole in the tunnel roof, and inserting a 6 m long pole through a gimbal to see if the waste could be moved (Figure 2). The design and safety case took 6 months to develop involving extensive design studies to ensure the tunnel roof could not be damaged, and operator training on a 2/3rds scale rig to ensure they could respond adequately to any incident, in particular to ensure they could respond rapidly to any incident of argon leaking out of the Silo or air leaking inwards. The operation was conducted as a 'command and control' regime, rather than rely on a heavily instrumented system.

The operation was very successful. Drilling the 0.5 m holes in the tunnel did not cause significant changes in oxygen concentration. Also, the pole moved the waste relatively easily. Subsequent operations used additional end appendages to sweep and cut waste. There was a great saving in the time and development costs used in this simple technique to move the waste from the tunnel.

PLUGGING AND SEALING OF TUNNEL AND CHARGE HOLES

Once the waste had been cleared from the tunnel the chargeholes were to be plugged and sealed so the argon would be retained in the compartments and not escape into the tunnel.

INACTIVE RIG WORK

A rig was constructed, building on previous experience of rigs to ensure that concepts worked before they were put into practice, and to train operators and installation staff.

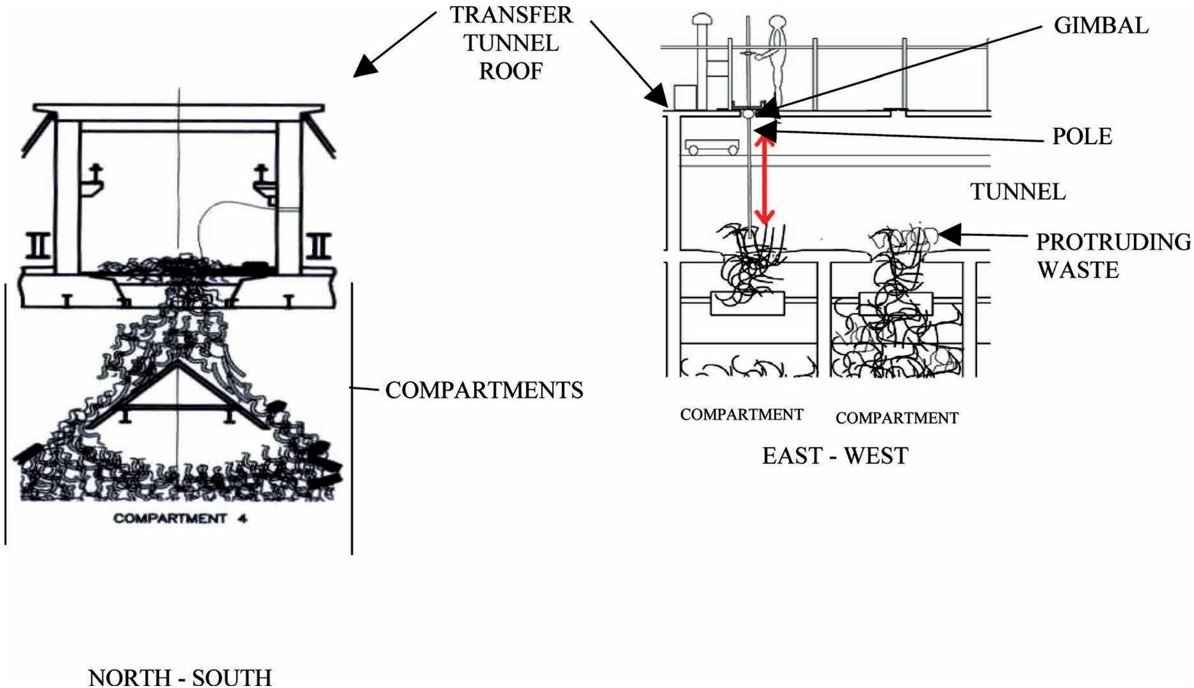

Figure 2. Cross sections through top of compartment and tunnel

Also, the rig was a valuable tool in convincing the Regulators that an adequate safety case could be made. The rig was full size for the tunnel and charge hole dimensions and 2/3rd full size in height from the ground (~12 m high). The rig was not filled with inert gas because of the asphyxiation risk, but all other aspects were kept as close as possible to the operating conditions. Every single task was rehearsed to ensure it could be carried out on the site. This proved valuable, for example a chain operated lifting beam was identified during the trial as having a gear ratio that caused lifting to take place ~1/10th of the required rate. Providing the correct ratio reduced the time spent on plant and minimised dose uptake. Also, tests were carried out on the sealant and the plugs to ensure that the plugs could meet the required sealing specifications with the set up pressure tested to ensure leaks were kept to a minimum.

Once the scheme had been finalised the operations team which were going to carry out the work on site were trained on the rig. This was intended to ensure that all personnel were fully aware of their roles and responsibilities. Identical personal protection equipment was worn on the rig.

The inactive rig saved the cost of time on the plant correcting problems, and minimised dose uptake.

WORK ON THE SILO

To allow tunnel entry the argon inerting was switched off and an air ventilation flow was passed down the tunnel using the main ventilation fan. This ensured that argon escaping from the compartments into the tunnel could not form a hazard to operators sealing the compartment chargeholes (NB these operators also wore breathing air sets and oxygen deficiency alarms, as additional backup).

The oxygen sampling pipe work had to be extended into the Silo to give a sampling point nearer the waste, as oxygen concentrations alarms were being triggered far too early by air seeping into the Silo. Repositioning the oxygen sampling points further down the compartments, but still above the waste level, allowed longer working times in the tunnel, whilst still ensuring the waste was kept inerted.

Once tunnel entries began it was discovered that the surfaces of the charge holes and concrete were in poor condition. As the final plugging required a flat surface to make a good seal then repairs were carried out using a combination of grout and several sealing products. Issues that were resolved during this period included ensuring protracted curing times did not occur and that flammable vapours could not build up in the confined space of the tunnel.

Plugging was carried out in three stages because of hoist and Silo weight and gas sealing restrictions. A first stage plug was installed which provided shielding, some sealing and provided an additional protection (to that of harnesses) from the risk of operators falling into the compartments. The second stage required large 'H' shaped frames being installed to spread the plug load. The final stage of plugging was then installed. These operations went well, and were faster than anticipated because of the operator training on the inactive rig.

Once the second stage trays had been installed the pressure in the compartments was lowered to approximately −10 mbarg to detect leaks. The leakage rate of each compartment was estimated by a combination of smoke pencils and by measuring the extract flowrate. Leaks were repaired using appropriate sealants. This became an iterative process with improvements being made after every running of the test. After several tests it was decided that all the improvements possible had been made to the outside roof surface of the Silo and attention turned to the confined space of the tunnel. The same process was completed there.

The extended dip legs on the compartment oxygen sampling pipework were intended to be removed once the sealing work had been carried out. However, this was not carried out because the flexibility they introduced might be required at a later date if higher air in-leakage rates occurred.

A test is planned to be carried out every year to show that there is no deterioration in the argon retention of the individual compartments. This is a requirement of the safety case to prove that the leakage rates from the Silo are acceptable.

Once all the sealing work had been completed then a false floor was put on top of the tunnel floor to allow better access and to protect the plugs beneath. The oxygen depletion monitoring sample point was moved to the interface between the tunnel floor and false floor, to give early indication of any new leakage from the compartments.

DEMOLITION OF TUNNEL

It was desirable to isolate the active ventilation system from the tunnel after plugging and sealing of the charge hole plugs. However, the tunnel remained a confined area because of the small possibility of adventitious leakage of argon from the compartments beneath. Therefore, the simple solution of drilling a number of holes in the tunnel walls was carried out. 16 holes were drilled at both ends of the tunnel at the top and the bottom to promote the flow of air into the tunnel from the outside through natural ventilation. The holes were sized so that the oxygen concentration would not fall below 19% even under the worst case conditions (i.e. all the inerting argon being delivered into the compartments leaking into the tunnel during stable weather conditions). The internals of the tunnel were sealed to minimise the possibility of radio-activity being released during demolition. The tunnel was scaffolded internally to allow for demolition, which was a combination of nibbling reinforced concrete and removal of the bricks individually. All waste was bagged prior to removal off site. It was found that very little activity has penetrated into the materials despite 50 years exposure.

BETA IN AIR INSTRUMENTS

Each of the six compartments has a beta in air instrument, which is intended to detect a fire in the compartment in the remote case where the argon inerting blanket is lost and there is an ignition source present in the Silo. The instruments draw gas from each compartment at a rate of 37 l/min (2.2 m^3/h) and then pass this back to the compartment, which is a significant percentage ($\sim$20%) of the inert gas injection rate.

Large variations in the oxygen concentrations in compartment 5 were seen during October 2004. After an investigation it was found that a hose on the inlet of the instrument was perforated and that this was passing air into the compartment. Once this had been repaired the oxygen concentration returned back to the normal levels. Also, it was found that oxygen concentrations continued to vary despite there being no identifiable changes in plant conditions, oxygen concentrations in some compartments would rise from 0.1% and sometimes exceed 2% for periods). Several mechanisms were investigated including the effect of variations in atmospheric pressure. A loose correlation was found.

Investigations continued, and it was postulated that leakage into the beta in air system could be causing some of the variations. The beta in air instruments were adaptated from instruments used to detect radioactivity in occupied areas, so did not need to be leak tight. Another theory was that the beta monitors were causing a mixing effect in the compartments.

To investigate further, the beta in air instruments were isolated for a short period if the oxygen concentration in a compartment was approaching 1.6% (the trigger level for investigation) In each case, the oxygen concentration quickly reduced.

Therefore, a second longer test was carried out where isolation of beta in air was compared to operation of those instruments under identical conditions. The conclusions were:

1. Switching off of the beta in air instruments lowered the oxygen concentrations at the sample point however the evidence for the mechanism which was causing this was not conclusive. It appeared that the mechanism was a complex combination of in-leakage, mixing and weather effects (specifically temperature)
2. The sample rate for the beta in air system is relatively high and this could lead to a large inflow of air into the compartments if the inlet pipe work were to be breached, which could overwhelm the inerting system

The beta in air instruments will therefore be replaced with combustion gas (carbon monoxide) monitors which have a much lower sample rate and are of a similar design to the oxygen monitors currently in place.

ARGON SYSTEM ‘A’ PLANT EQUIPMENT FAILURES

The argon storage and vaporisation system had been supplied as a package. British Nuclear Group (Sellafield) provided the connections to the Silo. There have been a number of problems which have occurred during the operation of the plant. These include:

1. Relief valves and bursting discs had operated several times – it was found that the operating pressures of the argon plant had been set too close to the design pressure of the system. This was adjusted to allow a more satisfactory margin
2. Also, some of the bursting discs had been damaged during installation. Therefore, they were replaced with cartridge style bursting discs which more resilient to incorrect installation

As a general principle it was recommended that vendor supplied plants should be operated as supplied. Any modifications to allow the plant to meet British Nuclear Group (Sellafield) requirements should be carried out as much as possible outside the vendor plant envelope.

ARGON SYSTEM 'B'

Installation of a second argon inerting system, System 'B', is underway. This will supply inerting argon to the top of each compartment and will supply the majority of the inerting argon. Argon System A will supply a small amount of argon to the compartments which is intended only to prove it is operational. System A will be able to take over if there are any failures in system B. All the learning from experience discussed above has been incorporated into the design of system B.

System B is designed to be fully seismically qualified up to a 1 in 10,000 year (0.25 g) DBE. It was intended to supply the system B argon storage vessel meeting this criterion. However this became problematic as supplier design and fabrication costs began to escalate. Therefore, that approach was changed to designing the concrete base slab to sit on seismic isolation bearings, which would dampen the vibrations from a seismic event. This also allowed a virtually standard vendor argon plant to be used with only minor modifications.

It was not possible to modify System 'A' to meet a 0.25 g specification, due to the cryogenic design of the double skinned argon storage vessels supplied at the time. It is interesting to note that the vessels met the 0.125 g criterion up to ~80% full. The safety case does not utilise this performance.

System 'B' will use a top entry inerting connection (as opposed to the bottom entry connection for system 'A'). This will be via an extended pipe into the top of each compartment which is designed bypass the top layer of oxygen rich gas and deliver the argon straight to waste mass. Also, this avoids the oxygen getting entrained in the argon and raising the overall oxygen concentration.

RETRIEVALS

The scheme for the retrieval of waste from the compartments is nearing finalisation. There are a number of points which will need to be considered in the choice of the retrieval scheme with regard to argon retention and asphyxiation.

During retrievals there will be a number of modules used for the retrieval of the waste. Penetrations will be made into the compartments for these modules and a good seal will have to be made to ensure there is little or no leakage in at that point. The seal will also need to be relatively flexible to ensure that any differential movement between the Silo and the module does not increase the leakage rate. A very good seal will also need to be provided once the module has been detached to ensure the leakage rate is very small.

Air locking will be required for the import and export of items into the argon filled areas of the module for the purposes of argon retention. If a large container, full of air, is imported into the module, then the oxygen concentration would rise quickly on the introduction of this air into the system. Assessments are required to determine the hazards generated, and the effect on retrieval rate waiting for the oxygen concentrations to stabilise. Design work continues to decide on where in the retrieval or downstream process that the transition from argon to air should take place, balancing nuclear safety, asphyxiation risks and operability drivers.

Because of the continual close management required to maintain low oxygen concentrations, there is concern that retrieval may result in higher oxygen concentrations, and lengthen retrieval times, hence prolonging radiological and asphyxiation risks. It is not desirable to increase significantly the argon throughput on the plant. Therefore, desk top studies are about to begin to explore the conservatism in the flammability limits applied to the plant, to determine if the current oxygen controls targets are overly pessimistic, and might be increased whilst maintaining adequate safety.

APPLICATION OF LEARNING TO OTHER PLANTS

Because the original Silo building was designed to be ventilated naturally, considerable effort had to be made to improve the gas tightness of the structure, including coating the reinforced concrete building with a sealant. This has been successful, because most of the outer surfaces were accessible. Leakage through the base has been minimal. Because of the design of the base, it is possible to interspace test. This might not be possible on other plants, which would affect the viability of inerting.

Inerting remains successful, because of continuing close management and the selection of argon which is less sensitive to perturbations than lighter gases such as nitrogen. However, 4 years after inerting began, variations in the oxygen concentrations in the compartments continue even with the improvements carried out. Inerting of the compartments is reliant on the rate of inerting into the compartment and the leakage rates. It is to be expected that as the Silo ages, leakage will increase. It is not possible to determine the rate of increase of leakage over extended time periods; therefore continued vigilance is required. It is likely that these issues of continued performance will vary from plant to plant.

Significant changes continue to be made to the structure of the Silo as it is readied for emptying. Each physical change has affected the oxygen concentration because of the requirement to maintain a very slight depression relative to atmosphere (-10 to -50 Pa). Recommissioning is often involved after each change, together with identifying and sealing new leak paths. This is time consuming requiring new operator training, and modifications to the safety case. Most nuclear retrieval operations have to utilise batch processes, where the materials are transported by flask. Airlocks will usually be the better way of minimising the effect of linking these flasks to the building. Where this is not practicable because of weight or space restrictions, the flask should be inerted. If this is not practicable, then the amount of air introduced to the plant from the flask will affect the management of the oxygen concentration significantly, with potential safety and throughput issues. Therefore, desk top studies are about to begin to explore the conservatism in the flammability limits applied to the Silo, to determine if the current oxygen controls targets are overly pessimistic, and might be increased whilst maintaining adequate safety. This work will be of benefit to other plants.

Operating the Silo at slight depression is affected by weather conditions. Variations can be significant when mild weather fronts pass over. The effects of weather variations on other plants could be similar, and identification of the reason for the variation is important to avoid wasted effort.

The structure and instrumentation on the Silo are relatively simple. Nevertheless, small leaks, for example on instrument impulse pipes, have affected oxygen concentrations and it has been difficult to assess the significance of the leaks, and then to identify and seal them. Such issues will be significant when considering the viability of long term inerting on more complex structures, where there could be hundreds of penetrations.

Asphyxiation issues have been dealt with successfully on the Silo. Continuing vigilance is required. When retrieval begins, continual activities will be taking place on the plant, in particular, seals will be required to be broken and made on a daily basis, because of batch processing. The asphyxiation risk will be increased by these activities.

Predictions on behaviour of gas tightness and structural performance can often be inaccurate when dealing with old plant, because of lack of hard evidence. Therefore, contingency arrangements need to be in place, unless the activity to be undertaken can be reversed. Once suitable arrangements are in place, the activity should proceed, with short term activities being managed in a 'command and control' regime to cater for any new issues that may arise during the activity. The justification to proceed is that the plant is already operational and un-necessary further delay means the risk remains in place for longer. It is noted that safety management systems can encourage delay (particularly during approval of safety documentation), because they are written usually for new plant where delay does not incur risk as the plant is not yet operational.

The experience of inerting the Silo has proved that it can be carried out successfully. However, the Silo is a relatively simple structure, and despite that, many difficulties have had to be overcome to maintain inert conditions. It is to be expected that more complex structures will significantly increase the difficulty and reduce the possibility of success. Such difficulties will be compounded if the structure has to be inerted for periods of years. Batch retrieval will add perturbations which could be significant enough to affect throughput and viability, together with asphyxiation hazards every time seals are broken. Therefore, inerting should not be seen as the 'gold standard' of hazard management in these circumstances.

CONCLUSIONS

Predictions on behaviour of gas tightness and structural performance can often be inaccurate when dealing with old plant, because of lack of hard evidence. Therefore, contingency arrangements need to be in place, unless the activity to be undertaken can be reversed. Once suitable arrangements are in place, the activity should proceed, with short term activities being managed in a 'command and control' regime to cater for any new issues that may arise during the activity.

Modifying an old building to be gas tight is likely to be successful only if access to all surfaces is possible to enable sealing and repair. If access to the base for testing or sealing is not possible, then the viability of inerting will be in doubt.

Inerting of the Silo remains successful, because of continuing close management and the selection of argon which is less sensitive to perturbations than lighter gases such as nitrogen. However, 4 years after inerting began, variations in the oxygen concentrations in the compartments continue even with the improvements carried out. It is to be expected that as the Silo ages, leakage will increase. It is not possible to determine the rate of increase of leakage over extended time periods; therefore continued vigilance is required.

Significant changes continue to be made to the structure of the Silo as it is readied for emptying. Each physical change has affected the oxygen concentration because of the requirement to maintain a very slight depression relative to atmosphere (-10 to -50 Pa). Recommissioning is often involved after each change, together with identifying and sealing new leak paths. This is time consuming requiring new operator training, and modifications to the safety case.

Operating the Silo at slight depression is affected by weather conditions. Variations can be significant when mild weather fronts pass over. The effects of weather variations on other plants could be similar, and identification of the reason for the variation is important to avoid wasted effort.

The structure and instrumentation on the Silo are relatively simple. Nevertheless, small leaks, for example on instrument impulse pipes, have affected oxygen concentrations and it has been difficult to assess the significance of the leaks, and then to identify and seal them. Such issues will be significant when considering the viability of long term inerting on more complex structures, where there could be hundreds of penetrations.

Most nuclear retrieval operations have to utilise batch processes, where the materials are transported by flask. Airlocks will usually be the better way of minimising the effect of linking these flasks to the building. Where this is not practicable because of weight or space restrictions, the flask should be inerted. If this is not practicable, then the amount of air introduced to the plant from the flask will affect the management of the oxygen concentration significantly, with potential safety and throughput issues.

Asphyxiation issues have been dealt with successfully on the Silo. Continuing vigilance is required. When retrieval begins, continual activities will be taking place on the plant, in particular, seals will be required to be broken and made on a daily basis, because of batch processing. The asphyxiation risk will be increased by these activities.

The experience of inerting the Silo has proved that it can be carried out successfully. However, the Silo is a relatively simple structure, and despite that, many difficulties have had to be overcome to maintain inert conditions. It is to be expected that more complex structures will significantly increase the difficulty and reduce the possibility of success. Such difficulties will be compounded if the structure has to be inerted for periods of years. Batch retrieval will add perturbations which could be significant enough to affect throughput and viability, together with asphyxiation hazards every time seals are broken. Therefore, inerting should not be seen as the 'gold standard' of hazard management in these circumstances,

REFERENCE

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