Liquor Activity Reduction (LAR) Programme – 12397

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ABSTRACT

Waste material from the reprocessing of irradiated fuel has been stored under water for several decades leading to the water becoming highly radioactive.

As a critical enabler to the decommissioning strategy for the Sellafield site, the Liquor Activity Reduction (LAR) programme has been established to provide a processing route for this highly radioactive liquor.

This paper reviews the progress that has been made since the start of routine LAR transfer cycles (July 2010) and follows on from the earlier paper presented at WM2011. The paper focuses on the learning from the first full year of routine LAR transfer cycles and the application of this learning to the wider strategies for the treatment of further radioactive liquid effluents on the Sellafield site.

During this period over 100,000 Curies of radioactivity has been safely removed and treated.

INTRODUCTION

Waste materials associated with irradiated nuclear fuel reprocessing are stored underwater in the Magnox Swarf Storage Silos (MSSS) at the Sellafield site in Cumbria. As a consequence of the underwater storage, the water has become highly contaminated with radioactive material. The Liquor Activity Reduction (LAR) programme has been established to reduce the radioactive content of this liquor.

The LAR programme provides several benefits: reducing the immediate hazard associated with the radioactive liquor itself, improving the conditions in which future decommissioning work will be undertaken by reducing the localised radiation dose rate and, very importantly, more efficiently utilising the Sellafield Ion Exchange Effluent Plant (SIXEP), the main abatement facility on the Sellafield site.

Central to the success of the Liquor Activity Reduction (LAR) programme is the utilisation of existing infrastructure on the Sellafield site. Although this has enabled early commencement of hazard reduction at MSSS, this approach requires significant management control and oversight.

The LAR programme has been successfully underway for just over a year and the experience and knowledge gained during this period is helping to inform future liquid effluent strategies on the Sellafield site.

THE LAR PROCESS

Batches of radioactive liquor are transferred from MSSS to the Effluent Distribution Tank (EDT) where the liquor is conditioned, sampled, analysed and sentenced prior to being transferred to SIXEP. The liquor is then further conditioned and treated at SIXEP to remove key radioactive species by ion-exchange prior to discharge of the effluent to the environment (sea). This sequence, referred to as the 'LAR transfer cycle', is illustrated in Figure 1.

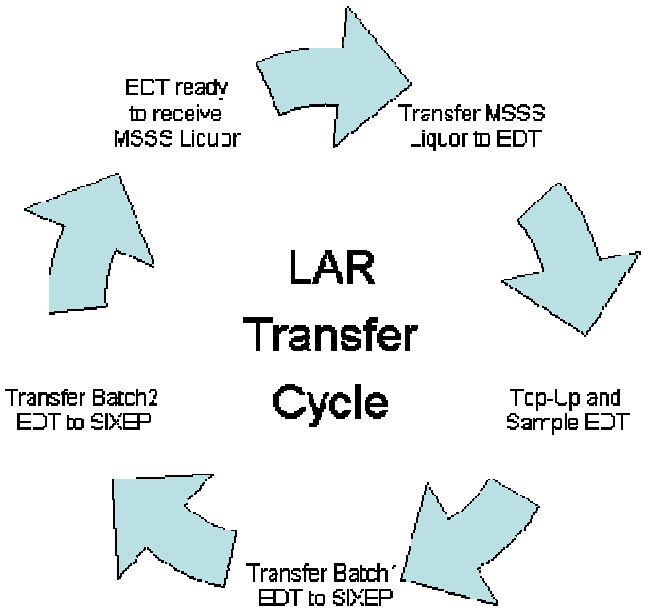

Fig. 1. LAR Transfer Cycle

The initial feasibility of the LAR transfer cycle was demonstrated by full scale trials completed in 2006/2007. Although successful, this trial was undertaken under temporary, limited duration, arrangements.

In order to undertake the LAR transfer cycle as a routine operation it was necessary to undertake a full assessment of the process across the three facilities leading to the implementation of new permanent arrangements across MSSS, EDT and SIXEP. As part of the implementation various equipment upgrades were undertaken, new operational procedures developed and comprehensive training delivered [1].

Routine LAR transfer cycles commenced in July 2010.

REVIEW OF PERFORMANCE

From July 2010 to December 2011, a total of 42 LAR transfer cycles have been completed. The following sections review performance during that period in terms of hazard reduction, schedule adherence, process performance and learning. Following this review, consideration is given to challenges facing the LAR programme in the future.

Hazard Reduction

As part of each LAR transfer cycle, the liquor removed from MSSS is replaced with fresh water. Over time this leads to a gradual reduction in the radioactive concentration of the MSSS liquor, hence reducing the hazard presented.

From the 42 LAR transfer cycles completed to date, Table I illustrates the quantity of radioactive liquor removed from MSSS, transferred from EDT to SIXEP and treated at SIXEP.

Table I. Summary of Radioactivity Transfers and Removal

	Radioactivity	
Description	**TBq**	**Curies**
Transferred from MSSS to EDT	3991	107853
Transferred from EDT to SIXEP	3836	103666
Removed by ion-exchange at SIXEP	3797	102629

The difference between the quantity of radioactivity transferred from MSSS to EDT and transferred from EDT to SIXEP relates to the radioactivity maintained in the liquor heel at EDT and at present this represents ~6% of the radioactivity removed from MSSS. As further LAR transfer cycles continue the heel concentration will diminish as the concentration of MSSS liquor reduces.

The difference between the quantity of radioactivity transferred from EDT to SIXEP and of that removed by ion exchange prior to discharge to sea is due the assumption, supported by plant data, that SIXEP removes >99% of radioactivity fed.

Figure 2 illustrates how the actual liquor concentration in MSSS has changed during the LAR transfers cycles completed so far. This compares well with the expected changes predicted by the LAR process flowsheet. At this stage, the indication of a reduction in the overall concentration of the radioactive liquor at MSSS is provided by evidence of concentrations in the facility equalising.

Having equalised, it will be during the next 2 years of transfers that the reduction in the overall concentration will become apparent.

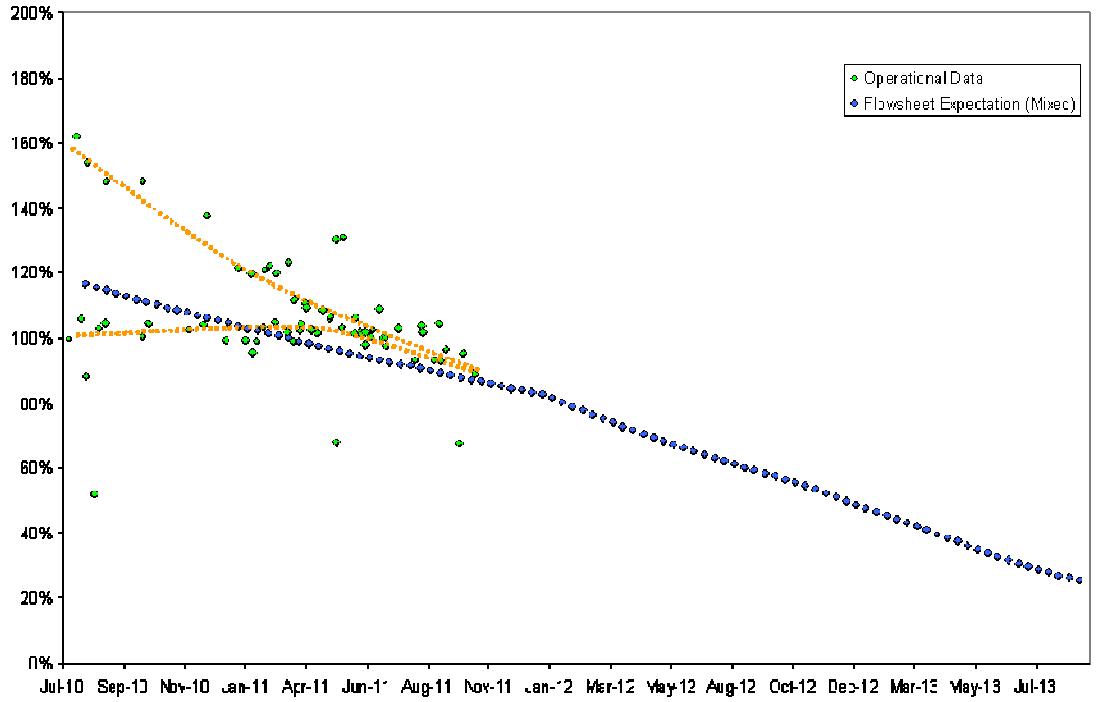

Fig. 2. Illustration of the Concentration Profile of Radioactive Species within the MSSS Facility during the LAR Programme

The LAR programme remains on target to achieve an approximate 10 fold reduction in radioactive liquor concentration over approximately 100 LAR transfer cycles.

The changes in concentration in the different parts of the MSSS facility have also been reviewed to assess the leaching rate from the stored waste material. The review has confirmed that leach rate is in the expected range and that the repeated cycles of dilution have not led to any unplanned increases in leaching.

Schedule Adherence

Liquid effluent management is crucial to many of the future decommissioning strategies at Sellafield site. The LAR programme therefore provides the first opportunity to establish expected productivity levels based on realistic plant performance. This performance provides important data that will inform decisions for future scheduling assumptions and risks for LAR transfer cycles and other essential decommissioning effluent streams.

The ability to maintain schedule adherence during the first year of LAR transfer cycles has depended on both the availability of the key plants (MSSS, EDT and SIXEP) and performance of other supporting infrastructure on the Sellafield site,

in particular, Analytical Services who provide the comprehensive sample analysis service.

Overall, the 42 LAR transfer cycles were completed during a 72 week period, including the initial active commissioning tests. Table II summarises losses during the 72 week period in order to provide an indication of the productivity achieved.

Table II. Summary of LAR Transfer Cycles Productivity

Description	
Calendar Weeks Available (A)	72
Planned Shutdown Weeks (B)	18
Unplanned Shutdown Weeks (C)	6
Production Weeks Available (D) = (A-B-C)	**48**
Number of LAR Transfer Cycles Completed (E)	**42**
Productivity (F) = (E/D)	**0.88**

As can be seen from Table II, LAR transfer cycles were completed in all but 6 of the production weeks available representing a productivity of nearly 90%.

This is considered exceptional performance, especially considering that the completion of LAR transfer cycles depends on both; aligning multiple independent plant shutdowns and operational resources, and, responding to the normal day to day availability issues that arise in any operational facility.

There were no common causes for the 6 production weeks lost.

Critical to achieving the high level of productivity has been the ‘command and control’ framework which has been implemented. The framework requires input from each facility and other stakeholder groups both during the planning of the next LAR transfer cycle, typically in the week preceding a planned transfer, and for the final ‘go/no go’ decision meeting on the day of each transfer. This approach has lead to proactive efforts from all parties to identify as early as possible clashes so that mitigating action can be taken.

Additionally, these regular communications have had a positive effect at bringing personnel from the different facilities and stakeholder groups together to work as a team to deliver LAR transfer cycles. Such team working is the essential ingredient to delivering work of this kind which has multiple interfaces and competition with many other high priority work faces.

Process Performance

The successful completion of LAR transfer cycles depends on ensuring that a number of process limits and constraints are met, including facility specific requirements and the SIXEP Conditions for Acceptance (CFA) for receipt of radioactive liquor.

Compliance with the SIXEP CFA is particularly relevant as SIXEP provides ultimate abatement for the MSSS radioactive liquor in line with meeting legal environmental authorisations for discharges.

As illustrated in Figure 3, the MSSS radioactive liquor must be diluted in the order of 100 fold to ensure its concentration is reduced sufficiently to meet the SIXEP CFA. This is completed in 2 stages: (1) 5 fold dilution at EDT and (2) 20 fold dilution at SIXEP. The key decision point for the process is made when analysis results are available from sampling at EDT. Thus EDT sampling is a real time activity for the LAR transfer cycle.

	MSSS		EDT		SIXEP
Day 1	Transfer to EDT **Conc[a] = A**	→	Receive from MSSS **Conc = A / 5**		
Day 2			Sentence Sampling		
	SENTENCING 'HOLD POINT'				
Day 3	Trending Sampling		Transfer to SIXEP **Conc = A / 5**	→	Receive from EDT **Conc = A / 100**
Day 4			Transfer to SIXEP **Conc = A / 5**	→	Receive from EDT **Conc = A / 100**
					Trending Sampling

[a]Conc = Liquor Concentration

Fig. 3. Illustration of LAR Transfer Cycle and SIXEP CFA Compliance

The Sellafield site Analytical Services department has performed a critical role in the analysis of samples to support real time sentencing from EDT. The quantity of samples and types of analysis performed has represented a significant increase in workload. This increase in workload has presented challenges to a number of the analytical methods employed requiring close consultation to enable their closeout.

From the limits and constraints, the LAR process flowsheet was developed in conjunction with the SIXEP chemical model to model the effect of LAR transfer cycles on the chemistry of the liquor in each facility.

Previous to the start of LAR transfer cycles, there was limited plant data available from previous sampling and analysis campaigns. It was therefore important to establish a comprehensive database of liquor analysis as the LAR transfer cycles proceeded to allow comparison with the LAR process flowsheet. This would also provide a more comprehensive dataset for flowsheet prediction on the behaviour of processing of such liquors. This is very important as similar liquid effluent streams will arise during future decommissioning activities.

To establish the requirements for the comprehensive database, detailed assessments were undertaken which included; a Data Quality Objectives (DQO) review and, a campaign of sampling and analysis to establish ‘baseline’ data prior to the start of LAR transfer cycles.

The completion of 42 LAR transfer cycles has enabled a comprehensive database of sampling analysis to be compiled and is ongoing. Review of the database indicates that at present the effluent chemistry is behaving largely as expected.

MSSS Process Chemistry

The LAR programme includes requirements to monitor and trend key parameters within the MSSS Facility which may be affected by the introduction of the LAR process. Such parameters include pH measurements, concentration of active species and competing ions to the SIXEP ion exchange process amongst other soluble species.

The taking of samples and the review of the information provided by Analytical Services is key to ‘approving’ the transfer of liquor from the MSSS facility to EDT and SIXEP. This approval is based on predicting that the resulting liquor within EDT will meet the SIXEP CFA. Review of these predictions on receipt of actual sampling results has confirmed that the MSSS Process Chemistry is not being adversely affected by the transfers.

EDT Process Chemistry

Once the transfer and conditioning of liquor at EDT has been completed, a sample of the finalised liquor is obtained to provide key information which initially enabled the onwards transfer of liquor to SIXEP. As operating experience has accumulated from actual sampling results it has become possible to predict with high confidence how the EDT process chemistry will change as a transfer progresses. This has enabled the decision to transfer from EDT to SIXEP to be taken based on predicted data, as opposed to sample sentenced batches, therefore enabling more efficient transfers. Sample results are then subsequently reviewed against these predicted values to ensure that the methodology being utilised to sentence liquor transfers remains valid.

SIXEP Process Chemistry

Performance of the SIXEP process requires feed liquors to meet the CFA. This ensures that the effluent condition entering the process will not adversely affect the technology which provides the abatement to radioactive discharge.

The technology employed to remove radioactive species from the SIXEP effluent is firstly via sand bed filtration and secondly via an ion exchange material. Performance of this process depends on several key factors including liquor concentration, pH, flow rates and ion exchange material condition. At intervals determined by a defined management assessment procedure, the ion exchange material is replaced to ensure the optimum efficiency for removing radioactive contamination from the effluent is maintained.

Compared to pre-LAR operations at the SIXEP facility, the ion exchange material is now removing approximately double the quantity of radioactivity before requiring replacement. This increase demonstrates a more efficient use of the ion exchange material and, represents a significant improvement and demonstration of SIXEP's overall capability to process such challenging effluents streams without adverse consequence.

LEARNING

Communications

The LAR programme is particularly unique in that the three independent facilities (MSSS, EDT and SIXEP) all have to be aligned to enable LAR transfer cycles to be initiated and completed. This alignment is required as there is no 'buffer' storage capability between facilities and so the whole of the route must be available before committing to the next transfer.

It has therefore been essential to establish effective communications between all the plants. This has enabled a full appreciation of the constraints faced in each

plant area to meet both LAR programme requirements and wider Sellafield site priorities.

Importantly, this focus on maintaining engagement from all three plant areas has continued and not reduced as successful transfers have continued. This ensures that, when unexpected issues do occur, all stakeholders can be immediately engaged to minimise any disruption.

The high level of importance placed on inter-plant communications has been rewarded through the high production level observed.

Liquor Chemistry Analysis

The LAR programme has generated a highly comprehensive and relevant dataset for the management of MSSS and similar effluent streams. This has enabled extensive data to be available to other future feed streams and has also provided detailed evidence when any issues regarding the liquor chemistry have arisen.

This comprehensive dataset represents a ‘best practise’ on the Sellafield site.

As part of the project command and control arrangements for demonstrating compliance with the SIXEP CFA, a LAR SQEP committee, comprising key representatives from all plants involved, has been created to provide a formal basis for reviewing the results from sampling, particularly if unexpected results occur, or to consider any other relevant effecting issues. This has enabled the timely review of issues and provided a basis for obtaining agreement for continued transfers.

The LAR SQEP committee has been judged to be very effective and is now being used as the ‘model’ for managing other effluent streams.

FUTURE LAR PROGRAMME

Liquor Mixing at MSSS

Currently, MSSS is quiescent and the behaviour of the liquor chemistry during the completed LAR transfer cycles reflects this.

In the coming year mixing of the liquor within the MSSS facility is to be introduced. Mixing is required for a number of reasons and one benefit will be to equalise concentrations across the facility more quickly, thus making each LAR cycle more efficient and therefore increasing the rate at which the radioactivity inventory in MSSS is reduced. However, mixing also has the potential to cause changes to the existing liquor chemistry and how the liquor chemistry may behave as future LAR transfer cycles proceed.

In anticipation of this, detailed assessments have been undertaken and predictions of likely chemistry behaviour made. To support this, a new set of baseline sampling will be undertaken building on the dataset already accumulated. Once mixing commences additional analysis will be undertaken and, for a period, real time sentencing based on MSSS sampling will be undertaken prior to making MSSS to EDT transfers.

EDT Additional Feeds

Several additional feeds to EDT are due to be introduced in the coming years.

The success of the LAR programme to date provides confidence that the new feeds can be integrated into the existing arrangements for managing EDT receipts and transfers to SIXEP.

However, integrating such feeds will require updates to procedures used to demonstrate SIXEP CFA compliance and will increase the need for detailed scheduling of feeds to maximise EDT and SIXEP throughput whilst achieving decommissioning targets. In the short term, integrating new feed streams has the potential to limit the LAR programme while tests are completed to demonstrate the impact of a particular feed stream at both EDT and SIXEP.

CONCLUSIONS

The past year has witnessed the very successful introduction of the LAR programme. This has lead to hazard reduction at MSSS and demonstration that the SIXEP facility can meet the significantly increased challenge that the LAR programme represents. Part of the success has been the ability to predict and deliver a realistic production schedule with the availability of the MSSS, EDT and SIXEP facilities being central to this.

Most importantly, the LAR programme has been successful in bringing together key stakeholders to deliver this work while integrating with the existing, day to day, demands of the Sellafield site.

REFERENCES

1 Bourque, H., Le Clere, S (2011). The Complex Challenges of Treating Liquid Effluent from a Legacy Fuel Storage Silo at the Sellafield Site, Cumbria, UK. WM2011 Conference, March 7-11, 2011, Phoenix, AZ

LIST OF ACRONYMS

LAR	Liquor Activity Reduction
MSSS	Magnox Swarf Storage Silo
EDT	Effluent Distribution Tank
SIXEP	Sellafield Ion Exchange Effluent Plant
CFA	Conditions for Acceptance
DQO	Data Quality Objectives