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| **PROJECT ASSESSMENT REPORT** | | | |
| **Unique Document ID and Revision No:** | ONR-SDFW-PAR-22-003  Revision 3 | **CM9 Ref:** | 2023/31647 |
| **Project:** | Magnox swarf storage silo (MSSS) Retrievals | | |
| **Site:** | Sellafield | | |
| **Title:** | ONR’s Regulatory Position on MSSS Original Building Leak to Ground | | |
| **Nuclear Site Licence No:** | 103 | | |
| **Licence Condition:** | 34: leakage and escape of radioactive material and radioactive waste | | |

**EXECUTIVE SUMMARY**

Office for Nuclear Regulation (ONR)’s Regulatory Position on the Magnox Swarf Storage Silo (MSSS) Original Building (OB) leak to ground.

MSSS is a legacy intermediate level radioactive waste (ILW) storage facility on the Sellafield site. As a historic silo facility, it was designed and built with less of a focus on clean up and decommissioning than modern nuclear plants. The facility was constructed in four stages between 1964 and 1983 and has been in quiescent operation since the last bulk waste deposited in the 1990s. MSSS stores ILW from reprocessing operations in twenty-two reinforced concrete silos, comprising mostly of Magnox fuel cladding magnesium alloy swarf. The waste is stored under water to prevent ignition of the radioactive inventory and maintain temperatures within silos within an acceptable range. The cover water is radioactive due to dissolution of the ILW.

MSSS is one of the highest nuclear hazards in the United Kingdom and is subject to significantly enhanced regulatory oversight by ONR. The high hazard arises from shortfalls in substantiating parts of this ageing facility to modern design requirements, mainly for external hazards and the radiological consequences should the hazards be realised. The facility does not meet modern safety standards and as a regulator we have been holding Sellafield Limited to account to ensure the waste is removed and placed in modern, safe storage as quickly and safely as possible.

In the 1970’s OB was found to be leaking radioactive water below ground. The maximum liquor loss rate of around 3m3/day decreased to around 5m3/month over the decade; this being nominal cover water losses from evaporation and seasonal changes in waste bed depth. The Nuclear Installations Inspectorate, the predecessor organisation to ONR, required British Nuclear Fuels Limited, the licensee of the Sellafield site at the time, to address the hazard posed by MSSS by developing methods to remove and process the stored waste. Removing the waste would also remove the source of the leaking radioactive liquor.

The task of developing and implementing a programme to safely retrieve the bulk of MSSS waste has proven to be highly complex, taking over twenty years to get to the position where retrievals from the first extension commenced in April 2022. Completion of bulk retrievals is currently planned to take until 2045-50.

Sellafield Limited, the current site licensee, and key stakeholders, including ONR, recognised that preparations for retrieval and retrieval operations had the potential to re-open historic leak paths and/or introduce new ones. As part of the retrieval preparations, Sellafield Limited, developed a MSSS leak management plan. The plan set out how the company would manage the resultant risks should MSSS OB leakage recommence.

In November 2019, Sellafield Limited formally reported to ONR and the Environment Agency that they had data suggesting a potential leak to ground. The MSSS OB liquor loss rate had increased from 5m3/month to approximately 1.3m3/day. Sellafield Limited attributed the increased loss to a leak of radioactive liquor to ground and implemented the leak management plan. In April 2021, Sellafield Limited reported that the OB liquor loss rate had further increased to around 2.4m3/day. To date the loss rate has remained relatively constant at between 2.3-2.5m3/day. The leakage is anticipated to continue until the bulk of the OB waste is retrieved for storage elsewhere on site, a process that is planned to be completed between 2045-2050.

Later, Sellafield Limited informed ONR that routine civil inspection had identified a damp area on the exterior side of MSSS OB north wall. Routine inspections of MSSS north and south voids, which are located between the OB and first extension silos, identified a few isolated damp patches on the internal walls. The company determined that the risks arising from the damp patches to operators and the public were very low and did not require remediation. ONR was content with Sellafield Limited’s responses and considered that the events did not justify regulatory enforcement action.

Sellafield Limited is progressing options identified to mitigate OB leakage and enhance leakage monitoring. The company engaged national and international experts in identifying potential technologies and selecting options to progress. All the options will take several years to develop to the stage where they could be deployed. The company will also continue to develop understanding of leakage chemistry and migration as MSSS transitions to retrieving waste from all twenty-two silos.

Sellafield Limited implemented extensive oversight and governance of the management of OB leakage; all supported the company’s approach. This included the company’s Chief Technical Officer, internal regulator and Nuclear Safety Committee. The company commissioned an independent review of MSSS retrievals, which included consideration of the OB leakage. The company is currently developing their responses to the independent review findings.

Overall, Sellafield Limited’s judgement is that the risks to operators, the public and the environment arising from the OB leak continue to be reduced as low as reasonably practicable (ALARP).

ONR responded to the renewed OB leakage to ground with two joint regulatory letters (in association with the Environment Agency) outlining our regulatory expectations. This was followed by enforcement investigations. ONR’s investigation concluded with the issue of an Enforcement Letter to Sellafield Limited for shortfalls in compliance with Licence Condition 34 (leakage and escape of radioactive material and radioactive waste). ONR judged that Sellafield Limited had failed to ensure, so far as is reasonably practicable (SFAIRP), that the radioactive material contained within MSSS is adequately controlled or contained to prevent leakage. In addition, the action taken by Sellafield Limited aligns with expectations detailed within our Inspection Guidance relating to ageing, single skin containment facilities.

Associated with the enforcement letter, ONR raised a level two regulatory issue, issue 8145, detailing ten actions requiring Sellafield Limited to address the breach of LC 34. Sellafield Limited instigated and delivered an extensive programme of work to respond to regulatory concerns. Sellafield Limited’s responses to ONR’s regulatory concerns have been assessed by ONR specialist inspectors who provided me with advice on the adequacy of the responses.

I judge that Sellafield Limited has provided sufficient evidence from the completed and planned programme of work to support the claim that the risks from the OB leakage are reduced ALARP. Inspectors identified some lower safety- significant shortfalls that they have confidence will be addressed by Sellafield Limited’s planned future work programme. The inspectors also provided advice and guidance to the company. The inspector will monitor Sellafield Limited’s resolution of the shortfalls, and consideration of the advice and guidance using lower-tier regulatory issues.

I consider the company has provided evidence that support the claims that the leakage chemistry, monitoring, migration and associated risks to workers and the public are adequately characterised and remain low. Also, there is high confidence that MSSS civil structure is robust to very high leakage. The company has identified and are progressing options for mitigating/preventing leakage and further improving leakage characterisation and monitoring.

Overall, taking account of advice provided by ONR specialist inspectors, I judged Sellafield Limited’s responses were sufficient to support closing issue 8145. The evidence supported either closing the associated actions outright or by managing the shortfalls using appropriate regulatory tools. The safety significance of the recommendations is such that they can be addressed after acceptance of the ONR MSSS OB leakage regulatory position statement

I judged that Sellafield Limited has provided sufficient evidence to support the claim that the MSSS OB leakage is compliant with LC34, recognising the potential for leakage to continue for several decades until the bulk of waste is retrieved from the OB silos. Notwithstanding current compliance, Sellafield Limited has a programme of work associated with MSSS leakage that is anticipated to support continued compliance with LC34, in accordance with goal-setting regulation. Inspectors identified some shortfalls against LC34 compliance associated with the future programme of work, which will be monitored by lower- tier regulatory issues.

**Recommendations**

I recommend that:

1. The ONR Sellafield projects sub-division delivery lead accepts ONR’s regulatory position statement on Sellafield Limited’s management of the MSSS OB leakage.
2. The ONR Sellafield projects sub-division management board recommends endorsement for closure of regulatory issue 8145 to the SDFW Divisional Board.

On completion of the transfer of the MSSS OB leak sub-programme to the MSSS retrievals programme, the delivery leads for ONR Sellafield projects sub-division and Sellafield compliance, intelligence, and enforcement (SCIE) sub-divisions intend to transfer regulatory oversight of MSSS OB leakage from projects to SCIE.

**LIST OF ABBREVIATIONS**

ALARP As low as reasonably practicable

BAT Best available techniques

BNFL British Nuclear Fuels Limited

Cs Caesium

CSM Conceptual site model

C&SE Civil and structural engineering

CTO Chief technical officer

DMW Demineralised water

EWTU Engineered water top up

FE First extension (MSSS)

FS Fault studies

GERM Ground environment review meeting

GRR Guidance on Requirements for Release from Radioactive Substances Regulation

ILW Intermediate-level (radioactive) waste

INES International Nuclear and Radiological Event Scale

IRR17 Ionising Radiations Regulations 2017

LBM Liquor balance model

LC Licence Condition

LMfS leadership management for safety

MSC Management safety committee

MSSS Magnox swarf storage silo

NDA Nuclear Decommissioning Authority

NII Nuclear Installations Inspectorate

NI&IO Nuclear intelligence and independent oversight

NLR Nuclear liabilities regulation

NSC Nuclear safety committee

OB Original building (MSSS)

OBLM Original building leak management

OBSP Original building (leakage) sub-programme

ONR Office for Nuclear Regulation

RP Radiological protection

SAA Severe accident analysis

Sb Strontium

SCIE Sellafield compliance, intelligence, and enforcement

SEP Silo emptying plant

SFAIRP So far as is reasonably practicable

SLG Stakeholder liaison group

TBq Terra Becquerel

UK United Kingdom

Sv y-1 Micro Sieverts per year

mSv Milli Sievert (1000micro Sv = 1milliSv)

m3/day Cubic Metre per day

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Figure 1: Schematic of MSSS civil structure

Figure 2: Schematic section of MSSS Original Building silos

Figure 3 Schematic section of MSSS First Extension silos

1. introduction
2. The Magnox Swarf Storage Silo (MSSS) is a legacy waste storage facility on Sellafield site and one of the highest nuclear hazards in the United Kingdom. In November 2019, Sellafield Limited formally reported to ONR and the Environment Agency that they had data suggesting a potential leak to ground [1]. The liquor loss rate from the MSSS Original Building (OB) had increased from 5m3/month to around 1.3m3/day. The liquor loss rate further increased to around 2.4m3/day in April 2021 and up to date has remained relatively constant at between 2.3-2.5m3/day.
3. Sellafield Limited attributed the increased loss to a leak of radioactive liquor to ground. The radiological consequences were subsequently assessed the leak against the International Nuclear and Radiological Scale (INES) as a category two (incident) event [1].
4. In response to the leak, ONR and the Environment Agency issued two joint regulatory letters outlining their expectations for the management of the risks arising from the leak [2] [3] and undertook formal investigations. ONR’s investigation identified shortfalls against Licence Condition (LC) 34, leakage and escape of radioactive material and radioactive waste, concluding with issuing of an enforcement letter [4]. The enforcement letter required Sellafield Limited to address the actions attached to existing regulatory issue 8145.
5. LC 34 (1) requires Sellafield Limited to ensure, so far as is reasonably practicable (SFAIRP), that radioactive material and radioactive waste on the site is at all times adequately controlled or contained so that it cannot leak or otherwise escape from such control or containment. LC34 (2) requires Sellafield Limited to ensure, SFAIRP, that no such leak or escape of radioactive material or radioactive waste can occur without being detected, and that any such leak or escape is then notified, recorded, investigated and reported in accordance with arrangements made under Condition 7 (incidents on the site).
6. This report presents ONR’s regulatory position statement on Sellafield Limited’s management of the MSSS OB leakage. In particular, the report presents ONR’s judgment on whether Sellafield Limited is discharging its legal duties in respect of the MSSS OB leakage as they fall within ONR’s vires. The statement is based on ONR specialist inspectors’ assessments of Sellafield Limited’s responses to regulatory concerns.
7. BACKGROUND
8. The Magnox Swarf Storage Silo (MSSS) is a legacy waste storage facility and one of the highest nuclear hazards in the United Kingdom. The facility was constructed in four stages between 1964 and 1983 and has been in quiescent operation since the last bulk waste deposited in the 1990s.
9. MSSS consists of twenty-two reinforced concrete silo compartments (figure 1) containing approximately 10 000 m3 of mixed solid intermediate level waste (ILW) arising from reprocessing of irradiated Magnox nuclear fuel. The ILW is stored under water to mitigate the risk of igniting the Magnox fuel magnesium alloy swarf, which constitutes approximately 80% of the waste. The cover water is radioactive and is classified as ILW. The cover water needs to be topped up to counter, in the main, evaporative losses. During waste retrievals operations water will also be discharged into compartments from silo emptying plant (SEP) cave contamination control washings. Operators monitor and control silo liquor levels and monitor the liquor loss rates. Excess liquor is transferred to the site’s aqueous active liquor treatment facilities to remove activity to comply with legal limits before discharge to sea.
10. In the 1970’s, excavation work for construction of the first extension (FE) revealed high levels of activity around the OB civil structure base figures 1 and 2). The source of the activity was attributed to a leak of contaminated liquor, probably from a wall to base construction joint. Around the same time operators identified that the OB liquor loss rate had increased rapidly from around 5m3/month to a maximum of around 3m3/day. The rate subsequently decreased to around 1m3/day after six months, gradually reducing back to 5m3/month over the decade. The liquor losses more than 5m3/month were attributed to the leakage to ground.
11. The Nuclear Installations Inspectorate (NII), the predecessor organisation to ONR, investigated the leak, culminating in the publication of a public report into the leak [5]. The probable source of the leak(s) was judged to be through-thickness cracks in silo wall construction joints. The cause of the leakage was attributed to thermal stresses in the silo walls from the exothermic corrosion of Magnox swarf. Investigations identified that the majority of the activity (principally Caesium (Cs) and Strontium (Sb) radionuclides) were bound proximal to the leakage point(s) by ion-exchange to clay minerals in the soil. In-ground monitoring and water sampling from on-site boreholes supported the claim that the migration rates for the majority of the leaked radioactive species were low.
12. NII concluded that there was no present danger from the leakage and therefore no need for urgent or immediate action to safeguard workers on site or the public. The position, however, was to be kept under close surveillance. The inspectorate also concluded that attempts to stop the leak would not be justified. This was because of the technical difficulties and risks to the civil structure integrity in implementing the identified leak mitigation options.
13. One of the regulatory requirements that NII placed on the licensee, British Nuclear Fuels (BNFL, the predecessor organisation to Sellafield Limited) was to develop methods to retrieve and subsequently process the waste stored in the leaking silo. The company has developed a programme to retrieve all the bulk waste stored in MSSS. However, the task of developing and implementing a programme to safely retrieve the bulk of MSSS waste has proven to be highly complex, taking over twenty years to get to the position where retrievals commenced in April 2022. Completion of bulk retrievals is currently planned to take until 2045-50. Sellafield Limited and key stakeholders have long recognised the potential for retrievals preparatory activities and operations to re-open historic leak paths or introduce new ones [6].
14. In 2013, Sellafield Limited’s third cycle long-term periodic review of MSSS civil and structural engineering integrity and ONR’s associated assessment [7] identified inadequate structural capacity to resist the forces which could result from a design basis seismic event or a thermal excursion above the current operating limits. Defects resulting from historic thermal excursions further reduce the ability of the OB and FE silos to resist forces which could result from a design basis seismic event or further thermal excursion. Future anticipated ageing and deterioration of the silo structures will further reduce the ability of the silos to perform their containment function.
15. ONR judges that the risk posed by MSSS is intolerable [8] and the facility is under significantly enhanced regulatory attention. The intolerable risks come from shortfalls in the seismic withstand (10-3 return event) of the OB and FE leading to loss of bulk liquor containment from an above-ground leak and spread of contamination. Key stakeholders, including ONR and the Environment Agency, support the waste retrievals programme to remove the intolerable risk posed by MSSS. Implicit with stakeholders’ support was the understanding that commencement of retrievals operations may cause recommencement of leakage to ground. Should the OB below ground leakage recommence, the strategy remained to deliver the earliest start of sustained waste retrieval from MSSS.
16. In November 2019 Sellafield Limited reported to regulators (ONR and the Environment Agency) that the MSSS OB liquor balance model identified that the liquor loss rate had progressively exceeded the 5m3/month trigger level for four successive months since July 2019 [1]. In December 2019, the liquor loss rate had stabilised at around 1.3m3/day (error band around ± 0.2 m3/day). In April/May 2020 the company reported that the loss rate had increased to around 2.1m3/day. Since that time the liquor loss rate has progressively increased, with periods of relative stability, and to date, the rate has varied between 2.3m3/day and 2.7m3/day.
17. Sellafield Limited confirmed that the increase in the OB liquor loss rates above the 5 m3/month (around the limit of detection) trigger was due to leakage to ground, possibly from the original leak site(s). The company reviews monthly the cumulative volume loss of liquor to ground and the associated activity. These data are reported to regulators in the MSSS OB leakage situation and trending boards.
18. On being notified of the increased liquor loss from the OB, ONR and the Environment Agency issued two joint regulatory letters and initiated enforcement investigations. ONR raised a level 2 regulatory issue (issue 8145) associated with the OB leak. The investigating inspector judged that from the evidence gathered during the investigation that the company had contravened Licence Condition 34 (leakage and escape of radioactive material and radioactive waste).
19. The inspector considered [4] that Sellafield Limited had failed to ensure, so far as is reasonably practicable, that the radioactive material contained within MSSS is adequately controlled or contained to prevent leakage. The inspector was content that the necessary responses required by Sellafield Limited to the breach were appropriately captured within the existing ONR Level 2 Issue and that no additional action was required at the time, or currently, over and above the actions contained therein. ONR inspectors continue to engage with the company on its programme of work to address regulators’ concerns.
20. Sellafield Limited instigated an extensive programme of work, under the control and guidance of the MSSS OB leakage sub-programme. ONR has continued to engage with Sellafield Limited to monitor the company’s response to the MSSS OB leakage and their progress in addressing regulatory concerns, primarily regulatory issue 8145.
21. In the assessment of the risks arising from MSSS OB leakage, Sellafield Limited has assumed that the leakage continues during OB waste retrieval operations, which will take several decades to complete. The company developed, and continues to revise, the safety case for retrievals operations that takes account the OB leakage. The safety case includes consideration of bounding leakage characteristics (increased liquor activity and leakage rate) and actions to mitigate the leakage.
    1. MSSS OB primary containment wall external damp patch
22. On 21 December 2021, Sellafield Limited informed ONR that routine civil inspection exterior side of MSSS OB north wall [9] had identified a damp patch. Subsequent investigations [10] by the company concluded that the patch was most likely caused by a combination of rainfall wetting and the thermal gradient through the wall. The activity was likely associated with legacy seepage from a construction joint.
23. The company judged that major loss of containment from the damp area could be discounted. The onsite and offsite dose estimations from chronic and acute aerial releases from the patch were judged to be trivial. Access to the damp area was restricted to further protect workers. They considered it was not appropriate to intervene on the damp patch. The company will continue to monitor the area and re-evaluate their approach in the event of significant deterioration.
24. ONR’s engagements with Sellafield Limited on the damp patch concluded that the event did not require regulatory action at the time on the basis of the evidence provided. The plant remained in a safe state and the damp patch was in existing radiologically classified area.
25. At subsequent radiological safety focused enquiries [11], the ONR inspector was content with the work undertaken to determine the source of the damp patch. The enquiry was supported by a civil and structural engineering specialist inspector to provide advice on civil structural integrity aspects of the company’s evaluation of the damp patch.
26. The RP inspector noted the ALARP challenges of undertaking more work would be disproportionate in terms of radiological risk to the operator when balanced against the potential benefits recognising that the damp patch is on the outside surface of the primary containment (an area of higher radiation levels).
    1. MSSS silo voids damp patches
27. There are two silo voids, north and south, between MSSS OB and FE silos. They were constructed during construction of the FE in part to provide radiological shielding gap from the OB leakage (a consequence of excavating contaminated ground). The voids were backfilled with concrete to approximately ground level, with some miscellaneous beta gamma waste (MBGW) stored in the remaining void space. Waste is not stored under water and there has been no evidence of hydrogen generation involving the MBGW.
28. Inspections of the voids identified a few isolated apparent damp patches on the OB-side walls. Subsequent investigations by Sellafield Limited via remote monitoring and sampling of the damp patches indicated that the likely cause of the South void damp patches was leakage silo liquor from C6. Identification of the source of the North wall damp patches was not conclusive. Further characterisation tasks will be undertaken in 2023/2024. Sellafield Ltd. currently consider that the most likely source is condensate from inside north void and not liquor from C5.
29. Sellafield Limited undertakes biannual inspections of the voids and plans to permanently cameras to monitor the damp patches. Sellafield Limited confirmed that to date there has been no change in conditions within the voids that would warrant additional action being taken.
30. Overall, ONR was content with Sellafield Limited’s investigations and responses to the MSSS OB and void damp patches [12], and no regulatory issues were raised on this matter. ONR continues to engage on the damp patches as part of routine interactions with Sellafield Limited
    1. MSSS Retrievals Programme
31. Sellafield Limited has developed a programme for the phased retrieval of the bulk waste from the MSSS silo compartments using three silo emptying plant caves (SEP). Retrievals commenced in April 2022 retrieving miscellaneous beta gamma waste from FE Compartment 10 using SEP 2 cave. The two other caves and supporting systems will enter service in subsequent years, with full retrievals capacity planned to be achieved by 2029.
32. The phased strategy progressively introduces, tests, and commissions new capabilities as they are required. The approach also improves management and control of modifications, and incorporates learning from experience, where appropriate. The programme is an integral part of the Sellafield site high hazard risk reduction (HHRR) plan. Retrieval of bulk waste is currently planned to be completed between 2045-50.
33. In outline, SEP caves will mechanically retrieve waste (grabbing and raking) from compartments. The retrieved waste will be placed into skips and exported from the cave and MSSS in a shielded transport packages for transfer by road to the on-site storage facility. At the storage facility the skips will be transferred into a storage container for long-term storage pending availability of a final disposal route.
34. ONR has implemented a strategy for permissioning key activities associated with MSSS retrievals programme.
    * 1. liquor activity reduction
35. As part of the preparations for waste retrieval, Sellafield Limited initiated a process to reduce the silo cover liquor radioactivity [13]. Liquor activity reduction (LAR) involves batch transfer of cover liquor from MSSS to the site ion exchange effluent plant (SIXEP) for treatment. Extracted radioactivity is stored in SIXEP and treated effluent is discharged to sea, subject to compliance with environmental permit requirements. The silos’ liquor levels are maintained within operational limits by water top up via the engineered water top up systems.
36. The benefits of LAR include reducing operational dose and reducing potential hazards from accidental releases or leakage. LAR is currently implemented for first and third extensions and there are plans to extend LAR to OB silos.
37. licensee’s safety case
    1. Safety case overview
38. Sellafield Limited reviewed the MSSS stream strategy ALARP position taking account of the renewed OB leakage to ground [14] [15]. The company judges that the MSSS Programme/Stream strategy is ALARP. The strategy remains to deliver sustained waste retrieval from MSSS as soon as is practicable to do so. That involves removing the source term that makes the facility intolerable, and in doing so removes the source of the OB leakage.
39. Sellafield Limited judges that the most significant risks [16] arising from continued operation of MSSS (including retrievals) relate to loss of containment and shielding resulting in worker and public dose as well as impact on the environment. The significant radiological hazards from continued operation of MSSS can be divided into three broad categories:

* Contamination: The hazard of contamination is managed by maintaining containment of activity. This encompasses activity in solid, liquid and gaseous forms including the use of abatement of aerial and liquid discharges.
* Radiation: The hazard of radiation is managed by maintaining containment, and by use of permanent and temporary shielding as required. In the event shielding cannot be provided, dose is managed by controlling time and distance.
* Criticality: The risk of criticality whist waste remains undisturbed is assessed as not significant.

1. A large loss of above-ground containment/shielding could result in significant radiological consequences and environmental impacts on and off site from radiation and contamination, and it is this risk that drives the overall ALARP requirement for retrieval and export of MSSS waste and silo liquor as soon as practicable.
2. Sellafield Limited assessed [17] the structural loading on the MSSS civil structure resulting from retrieval operations and identified that leakage below ground of silo liquor from within primary containment is a credible risk. The company considers the risk is only present for the OB and FE, recognising that these parts of the facility do not meet modern standards regarding secondary containment. In contrast, the second and third extensions are judged to have higher level containment, with full secondary containment and monitored interspaces. Loss of primary containment would be detected in interspace sumps.
3. In anticipation that OB leakage could recommence during retrievals preparations and operations, the company determined how the impacts of potential leakage from MSSS would be managed to continue to reduce associated risks ALARP and in compliance with BAT [18]. In determining the impact of recommenced leakage, Sellafield Limited anticipated that leakage could continue throughout OB waste retrieval operations, possibly at significantly higher rates.
4. The company concluded that in the event of OB below-ground leakage recommencing, the overwhelming priority would be removal of the waste. This was based on the predicted impact from both historical and future leaks having a risk to human health risk that is orders of magnitude lower than the risk posed by above-ground loss of bulk containment. Implementation of the options to mitigate or prevent leakage were all judged not to be ALARP, though the position would be subject to periodic review.
5. Sellafield Limited developed the MSSS leakage management plan [19]. The plan set out how the company would govern, organise, and deliver management of risks arising from below ground leakage from the facility from preparation to completion of bulk waste retrievals operations.
   1. Relative risks
6. The company judges that the human health risk from contaminated ground and groundwater at Sellafield, considering all historical leak sources in the order of 1x10-7 per annum [20]. Sellafield Limited has modelled potential consequences from a range of leak scenarios resulting from retrievals, including leak rates significantly higher than the peak leak rate inferred from the historical leak events. This modelling predicts a peak risk to off-site human receptors on the order of 1x10-9 per annum [21]. In terms of an annual dose exposure, this equates to a level several orders of magnitude below that calculated for the MSSS reference accident [22]. By comparison Sellafield Limited’s radiological safety assessment [23] for retrieval of MBGW from C10 identified the risk of above loss of liquor containment in the first extension silos from the consequences of a 1 in 1000 years frequency seismic event.
   1. sellafield Limited’s Arrangements for Leak Management
      1. MSSS leak management protocols
7. Sellafield Limited’s leak management plan protocols define three stages: stage 1 is routine operations; stage 2 is investigation of a suspected leak; stage 3 is recovery planning and response. At the end of stage 2 is a decision point with two scenarios defined: return to routine monitoring or move into event management protocols (in the event a leak is beyond the safety case envelope). The MSSS leak has been in stage 2 since 2019.
8. Principle 2 of the leak management plan considers the leak rate of a suspected or confirmed leak and recommends the management approach be reconsidered if the leak rate exceeds 25 m3/day, based upon its leak scenario modelling. This modelling postulates four scenarios: small (0.2 m3/day), medium (1.5 m3/day), large (10.8 m3/day) and very large (25 m3/day). The first three are based on historical observations of leak behaviour: ‘small’ equating to the liquor balance model (LBM) limit of detection, ‘medium’ equating to observed steady state behaviour during the 1970s historic leak, and ‘large’ equating to sump arisings from an event in the FE during 1978.
9. However, the ‘large’ scenario was “arbitrarily chosen to be between 2 and 3 times of maximum historical leak rates” and was intended to cover an extreme event that cannot reasonably be bound by historical observation. The ‘very large’ scenario is over eight times the peak leak rate of ~3 m3/day observed during the historical leak in the 1970s.
   * 1. Monitoring and reporting leakage
        1. In-plant monitoring
10. The MSSS safety case [16] requires the waste to be stored under water to prevent the risk of ignition. The company uses operating rules to control cover liquor levels in the compartments. The liquor levels are mainly affected by evaporation, barometric pressure, LAR, and, in the case of OB leakage, to ground. There is an engineered water top up system (EWTU) to maintain the liquor levels within operating limits.
11. During retrievals water from SEP internal cleaning will be discharged into the silos, increasing liquor levels. Liquor can be discharged from silos to downstream effluent treatment facilities to maintain liquor levels within the controlled limits. The EWTU and SEP cleaning systems use demineralised water to mitigate the risk of localised corrosion in the water distribution system.
12. Operators monitor EWTU frequencies and changes in liquor levels (as identified by installed level measurement instruments (pneumercators and radars) as the first-line identification of off-normal changes in behaviour. Sellafield Limited has recently developed a local guidance instruction [24] to aid operators’ initial assessment of the possible importance of any change in behaviour.
13. Sellafield Limited is adopting a two-tier approach to monitoring MSSS OB liquor losses. The first tier provides the structure for operators to rapidly identify and respond to off-normal behaviour. The 30-day rolling trend to monitor liquor loss rates, which provides in-time monitoring and smooths short-term transients to give a more representative view on liquor loss. The LBM is the second-tier monitoring tool and accounts for atmospheric and seasonal effects on liquor losses. The LBM is produced monthly, usually around two months in retrospect because of the time needed to collate and analyse inputs. The LBM will continue to be used to monitor the OB and FE liquor loss rates.
    * + 1. IN-ground monitoring
14. Within the ground, Sellafield Limited has installed an extensive network of groundwater monitoring boreholes across the site, 13 of which are located within 50m of MSSS [25]. The company has identified several boreholes at increasing distances from MSSS derived from the overall network and has defined sampling and analysis schedules at varying frequencies (monthly to annually) to obtain a diverse monitoring dataset of activity and groundwater migration to inform its decision making [25].
15. The company acknowledges there are limitations in using the entire dataset for leak detection purposes, and as such only consider groundwater borehole monitoring to provide information to support analysis and decision-making following identification of a leak by on plant detection methods [25].
16. In addition to the groundwater monitoring network, there is a network of in-ground gamma survey ‘blind tubes’ forming a curtain around and adjacent to the north, west and south walls of the OB. Monitoring of the blind tubes provides trending of spatial distribution of radioactive contamination inferred from gamma dose rate profiles with depth below ground.
17. The main purpose of the in-ground gamma monitoring is to assess current conceptual model understanding of in-ground contaminant behaviour (dominantly Cs-137) and provide information to support analysis and decision making. Sellafield Limited places no claims on this dataset for leak detection purposes owing to several factors, such as time-variable high dose-rate background (from existing contamination), in-ground attenuation, and potential for contaminant pathways to evade detection points.
18. Transition to stage 2 of the MSSS leak management plan included moving to enhanced monitoring and sampling.
    1. INES rating
19. Sellafield Limited categorised the MSSS leak at INES level 2 (incident) event. In February 2021, Regulators requested Sellafield Limited review the INES rating in view of the ongoing leakage [26]. Sellafield Limited concluded that the OB leak remains an INES 2 event and anticipates that retrievals from OB silos will have commenced before INES 3 criteria are reached; currently planned to commence in 2025. The company continues to keep the MSSS OB leakage INES rating under review.
    1. MSSS leak sub-programme
20. Following the increased OB liquor loss rates in 2019, the OB Leak Management (OBLM) sub-programme was established [27] to support the management of the MSSS leak to ground, under the protocols defined in the MSSS leak to ground risk management plan.
21. The remit of the OBLM sub-programme generally fell within the requirement of stage 2 of the management plan. Stage 2 requires that in the event of a leak below ground being suspected, communication and situational awareness protocols should be initiated to provide confidence to stakeholders (internal & external) that appropriate action is being taken. This stage also includes for further analysis of leak characteristics to validate behaviour against a series of guiding principles and parametric assumptions.
22. The remit of the OBLM sub-programme included the following:

* Increased vigilance on the plant and in the ground, with additional measurements.
* Optioneering to consider improved monitoring and characterization techniques, including engagement of the wider supply chain (plant and ground).
* Revalidation of the assumptions and underpinning of the risk management plan – has information or understanding changed, have technologies advanced.
* Optioneering more broadly across each leg of the environmental risk reduction hierarchy to seek to eliminate or reduce the consequences of the leak along with potential improvements to mitigation measures. Also engaging with the wider supply chain and other sectors to understand and develop alternative techniques which could be applicable.

1. Fourteen workstreams were established under the OBLM sub-programme. The key workstreams and their purpose were as follows:

* In-plant mitigation: The purpose of the workstream was to use modelling and R&D to assess multiple options for minimising / mitigating the leak within the MSSS facility.
* In-ground mitigation: The purpose of the workstream was to review and assess in-ground monitoring & characterisation and in-ground mitigation options.
* Land quality & baseline scheme: The purpose of the workstream was to feed into environmental risk assessments, carry out studies / surveys into enhancements in site monitoring, improvements to equipment, improved hydrogeological baseline and in-ground monitoring and characterisation. The baseline scheme reviewed and updated the current land quality reference scheme.
* Effluents: The purpose of the workstream was to review and update the technical baseline, sampling and modelling tasks to ensure the leak is correctly characterised and to provide support to the mitigation workstreams.
* Civil and structural engineering (CS&E): The purpose of the workstream was to complete underpinning technical engineering studies, support to mitigation and the long-term periodic review (Licence Condition 15, periodic review).
* Environmental: The purpose of the workstream was to support the other workstreams to ensure robust optioneering and decision making in respect to ensuring solutions can be demonstrated to be BAT and to undertake environmental assessments to support optioneering and support environment safety case production/implementation.
* Safety: The purpose of the workstream was to review and update the BAT and ALARP safety cases, confidence statements to support optioneering and produce sub-programme wide decision-making criteria to ensure a consistent approach
* Technology and Innovation: The purpose of the workstream was to use challenge statements to engage with the supply chain, including those in different sectors using the gamechanger process to pinpoint suitable technology and if appropriate develop them for deployment.
* Integration: The purpose of the workstream was to coordinate sub-programme activities, ensuring outputs were managed appropriately. This stream was responsible for the production and implementation of specific documents, for example, understanding the OB leak (current picture), development of revised protocols and the MSSS OB leak risk management plan.
* Plant interface: The workstream interfaced with the main MSSS programme looking at how to improve process monitoring to detect and quantify leak rates, above-ground monitoring and assurance activities, blind tube monitoring and data analysis.

1. The OBLM sub-programme was the Environment Agency and ONR’s main point of engagement with Sellafield Limited regarding the MSSS leak. The outputs of the sub-programme workstreams informed the company’s responses to issue 8145 actions. The sub-programme provided regulators with routine updates and technical engagements on the leakage.
2. The OBLM sub-programme was constituted for a finite time to address stage 2 of the leak management plan. The sub-programme provided the bulk of responses to regulatory issues/technical queries in July 2022, with longer-term work forming the forward programme. The sub-programme will be disbanded at with the workstream outputs being progressed by the MSSS retrievals programme or the Land Quality function..
   * 1. OBLM Sub-Programme key outputs
3. The key OBLM sub-programme outputs of interest to ONR were the responses to issue 8145 actions, in particular:

* Evidence to support the claim that the risks arising from OB leakage to ground remain reduced ALARP. This includes the resulting risks to workers on site and members of the public off site.
* The chemistry of the leakage to ground and consequential migration are adequately characterised and monitored.
* Evaluation of options to mitigate or eliminate leakage.
* Evidence to support the claim that the MSSS OB civil structure integrity remains robust to OB leakage throughout retrievals operation, including to very high leakage rates.
* Evaluation of options to improve monitoring and characterisation of the leakage, including developing innovative technology.
  + 1. Transition of the OBLM sub-programme into the MSSS programme

1. Sellafield Limited plans to close the OBLM sub-programme [28], on completion of the review of the management of OB leakage. Outstanding, longer-term tasks will be transferred to the MSSS programme, along with increased functionality aligned to the continued management of the leakage. These include:

* Progressing development /implementation of in-plant and in-ground leakage mitigation options.
* Progressing development /implementation of leakage enhanced monitoring and sampling techniques.
* Progressing development /implementation “gamechanger” emergent technologies.
* Creating the MSSS leakage oversight and advisory group.

1. The OBLM sub-programme identified several viable in-plant and in-ground leak mitigation options [29] the company is progressing. Two in-plant options are mechanical agitation to disrupt the flow of liquor through the waste and retrievals choreography (pattern and sequence in which SEP caves are deployed). In-ground leak mitigation options were divided into near-field (very close to the facility) and far-field (on site and remote from the facility). The company will also continue to develop understanding of leakage chemistry and migration as MSSS transitions to full retrieval of waste from all twenty-two silos.
2. The company is also progressing improvements to the MSSS in-ground monitoring, including investigating emergent technologies through the “Gamechanger”[[1]](#footnote-1) process. “Gamechangers” is an innovation programme designed to identify and develop cutting-edge technologies that could provide significant advances in the decommissioning of the Sellafield site.
3. The MSSS leakage oversight and advisory group is being created within the MSSS retrievals programme. The group is expected to ensure that the MSSS retrievals programme takes appropriate account of leakage in their plans.
4. Responsibility for progressing leak mitigation options will pass to the MSSS programme when the OBLM sub-programme is closed. Should Sellafield Limited decide to implement leak mitigation measures, ONR may choose to permission such activities dependent on their nuclear safety significance and in accordance with regulatory strategy and guidance.
5. ONR will continue to maintain close regulatory oversight of MSSS, including sub-programme work being progressed by the MSSS programme, in line with ONR’s strategy for regulating the Sellafield site.
   1. Oversight of the oblm sub-programme
6. The OBLM sub-programme has been subject to the company’s management and oversight requirements, including a hierarchical approach for key decisions [27]. This includes involvement of Sellafield Limited’s internal regulator [30], Nuclear Intelligence and Independent Oversight (NI&IO) and the Nuclear Safety Committee (NSC).
7. The 2022 Chief Nuclear Officer and NI&IO’s review of safety performance [31] presented to the NSC included consideration of MSSS OB leakage. In 2021, NI&IO’s oversight included a review in 2021 to determine the organisation effectiveness in supporting the ‘leak to ground scenario’ within MSSS. The review was followed up in 2022 with a further progress review. This concluded that whilst work continues to be delivered in line with the leak management plan, there are, as of yet, no immediately deployable solutions and therefore the retrieval programme remains the only viable mitigation option.
8. NI&IO’s main focus was on the processes for identifying, evaluating in-plant and ground leak prevention /mitigation options and the subsequent optioneering decisions. Sellafield Limited implemented their Chief Technical Officer’s (CTO) reviews for key optioneering decisions. These were known as “can we” (technical feasibility) and “should we” stages. The head of NI&IO, the Chief Nuclear Officer, was involved in both CTO reviews providing independent oversight of the processes.
9. The OBLM provided regular updates on MSSS leakage to the NSC. The revised MSSS stream strategy ALARP and BAT position was presented to NSC [32] [33] for consideration and advice. The committee noted the paper, offered no advice and requested additional context around one claim for consideration.
10. The OBLM sub-programme on-plant and in-ground mitigation measures were also presented to the NSC [33]. The committee was broadly supportive of the approach articulated. No points for consideration were provided.
11. Sellafield Limited has formed the MSSS Leak Oversight and Advisory Group [34] to support and advise the MSSS programme throughout delivery of the retrievals programme. The group’s remit includes providing oversight on the MSSS leakage forward planned work and delivering the MSSS leakage annual review.
    1. Independent review
12. Sellafield Limited commissioned an independent review of MSSS retrievals programme [35]. This focused on waste retrievals but also took account of the OB leakage. The independent review team drew on national and international expertise.
13. The key points of the review terms of reference were given as:

* *The review will consider the strategy for the management of nuclear and environmental risk associated with the MSSS facility and highlight areas for further consideration.*
* *Independence is key.*
* *The review is expected to take cognisance of historical reviews and in-flight programmes.*
* *The review is to:*
* *Confirm, if the current strategy associated with management of nuclear safety and environmental risk represents an appropriate strategy.*
* *In the context of nuclear safety and environmental risk management, highlight considerations for the SLC* [Site Licence Company] *as appropriate with regards the current strategic position.*
* *Highlight considerations for the SLC that may yield additional benefits compared with the extant strategy by:*

1. *Identifying unconstrained alternative approaches.*
2. *Assessing the alternative approaches recognising the current policy constraints on the programme, effectively undertaking a coarse screening of the unconstrained options.*
3. *Comparing viable alternative approaches identifying issues, threats and opportunities associated with each approach, including the suitability for integration within the Sellafield Enterprise Strategy.*

* *The review is to consider all aspects of the sub-value stream up to interim storage.*
* *Appropriate lines of enquiry are developed at initiation and shared with Sellafield Limited*

1. In relation to the OB leakage, the review team considered that there was more that could be done to address the leak. Of the twenty-two points made by the team for consideration by Sellafield Limited, one related directly to leakage. The team considered the bite strategy (removal of the waste using the SEP cave mechanical grab) could be simplified and prioritised to better address the leak.
2. In October 2022, the independent review team chair presented the findings [35] to Sellafield Limited and stakeholders, including regulators, for consideration. The company is currently considering the outcome of the independent review and are planning to respond to the findings accordingly.
3. ONR Assessment and engagement
4. ONR’s strategy for regulating the Sellafield site is identified in reference [36]. The strategy focuses on stimulating, facilitating and expediting hazard and risk reduction. Ensuring that the risks posed by MSSS leakage remain reduced SFAIRP is a key enabler for HHRR retrievals operations and the company’s legal duty, including complying with the requirements of LC34.
5. As MSSS project inspector I led ONR’s MSSS OB leakage intervention to gain assurance that Sellafield Limited is working to address regulatory concerns and is managing the risks arising from the MSSS OB leak to workers and the public are reduced SFAIRP. Throughout, I have been advised by ONR inspectors from the following specialisms assigned to this regulatory activity [37]:

* Nuclear liabilities regulation (NLR).
* Civil and structural engineering (C&SE).
* Chemical engineering and chemistry.
* Radiological protection (RP).
* Leadership and management for safety (LMfS).
* Fault studies (FS).

1. ONR’s strategy for delivery of the MSSS leak position statement is presented in decision record ONR-SDFW-DR-20-012 [37]. The contact records of ONR’s MSSS OB leak regulatory engagements are filed on CM9 folder 4.5.10373. Supporting documentation are filed in CM9 folder 4.4.2.25138. Key documents are collated in the MSSS OB leakage document tracker [38].
2. ONR’s intervention took cognisance that MSSS OB leakage could continue throughout OB waste retrieval operations, which could take several decades to complete.
   1. Project inspection
3. ONR has engaged with Sellafield Limited since being notified of the increased MSSS OB liquor loss rate. My role as MSSS project inspector was to lead ONR’s intervention on MSSS OB leakage. Throughout I have been supported by specialist inspectors. I have throughout liaised with the ONR retrievals SCIE nominated safety inspector, who leads on regulatory enforcement on MSSS.
4. ONR has worked cooperatively with the Environment Agency regarding regulatory responses to the MSSS OB leakage. This has included sharing relevant information and holding keep-in-touch meetings at working-inspector and senior leadership levels.
5. The key MSSS OB engagement forums are the MSSS leak stakeholders’ liaison group (SLG) and the MSSS OB leak stage 2 meetings. The SLG provides the platform for Sellafield Limited to present updates on the leak sub-programme activities and for regulators to challenge, monitor progress against issue 8145 actions (annex 1), raise queries and seek clarification. Sellafield Limited and ONR have held topic-specific meetings to investigate further key aspects of the OBLM sub-programme’s work. Queries raised by regulators are managed to closure by Sellafield Limited on the regulatory issues tracker.
6. Action 10 requires Sellafield Limited to demonstrate that the company has a resourced programme for undertaking and completing the tasks the company has identified in addressing regulatory issue 8145 actions 1 to 9.
7. Sellafield Limited initially responded slowly to regulatory concerns, due mainly to COVID-19 restrictions which came into force at the start of the company’s response. From mid-2020, Sellafield Limited’s responses markedly improved as the sub-programme was formed and started to develop the workstreams.
8. I gained sufficient evidence [39] that, in my opinion, Sellafield Limited had developed an effective and suitably resourced team that could confidently be expected to address ONR’s concerns. I therefore closed action 10 in July 2021.
9. MSSS waste will be retrieved from OB and FE silos using SEP 1 and 2. Space, operational and civil structural integrity are some of the constraints that make optimising deployments of SEP 1 and 2 complex. The whole process of optimising retrievals is known as choreography. Sellafield Limited will continue to review choreography throughout delivery of the retrieval programme.
10. The purpose of issue 8145 action 7 was to ensure OB and FE retrieval choreography includes appropriate consideration of the risks arising from OB leakage, recognising the need to prioritise waste retrieval. Sellafield Limited routinely updated ONR on the choreography review, which are recorded in contact records filed in CM9 folder 4.5.10373. Sellafield Limited’s review [40] included:

* Confirmation that SEP 1 and 2 can be deployed simultaneously on OB silos, though space constrains limit the extent of joint deployment.
* Confirmation that civil structural constraints preclude simultaneous deployment of SEP 1 and 2 on FE silos.
* Confirmation that simultaneous deployment of SEP 1 and 2 on OB silos would extend the overall completion the bulk retrievals from OB and FE silos. Also, the company has taken into account FE currently presents a higher risk than OB from loss of above-ground containment.
* Civil structural reviews have given further insights into waste removal choreography.
* Choreography was included in the in-plant leak mitigation optioneering [29] and is one of the options that will be progressed by the MSSS programme.
* Should techniques currently under development be successful in identifying the source(s) of OB leakage, Sellafield Limited may choose to prioritise emptying the relevant silo(s). However, the company would also consider delaying their emptying, for example to manage leakage activity concentrations.

1. Choreographing retrievals operations across MSSS is complex with many inter-related facets. Examples of the constraints include, civil structural constraints prevent emptying silos in one stage (solid waste could be removed in one stage, but liquor levels would need maintained across related silos), deploying SEP 1 and 2 simultaneously on FE. SEP 1 and 2 need to be positioned to enable movement via building cranes of waste packages and integrate with other construction/ maintenance /operational activities.
2. I reviewed Sellafield Limited’s response to issue 8145 action 7 [40] and took cognisance of evidence gained from routine engagements, and advice from the ONR C&SE specialist inspector’s assessment. I am content that Sellafield Limited has appropriately considered the effect of MSSS OB leakage on the OB and FE retrieval choreography. The in-plant options being pursued by the MSSS programme now includes consideration of OB leakage within retrievals choreography. Overall, I consider the company has provided sufficient evidence to justify closing action 7.
3. A key deliverable of Sellafield Limited’s response to regulatory concerns was evaluation and, where appropriate, implementation of options to prevent, minimise, mitigate, or remediate the consequences arising from OB leakage. ONR’s concern is captured in issue 8145 action 6.
4. Sellafield Limited regularly updated ONR on development of the response to action 6. I observed that the company:

* Adopted a structured staged approach to decision making based on established multi-attribute decision analysis.
* Engaged company and independent national and international expertise to influence and shape the scope of delivery and in reviewing the outputs.
* Adopted a collaborative holistic approach to delivery, ensuring shared understanding across the sub-programme workstreams.
* Adopted challenging oversight arrangements, including Sellafield Limited Chief Technology Officer’s review, NI&IO oversight, and submissions of key stages to the NSC for consideration and advice.

1. The leadership management for safety (LMfS) specialist inspector and I engaged with Sellafield Limited on delivery of the action 6 response [41]. The inspector provided me with advice on the adequacy of the company’s decision-making approach. The meeting discussion and previous engagements with the sub-programme provided us with confidence that the company had adopted and implemented appropriate structure, oversight and challenge to their decision making. ONR received assurance that the decision-making processes were undertaken by suitably qualified and experienced persons of appropriate disciplines.
2. A second LMfS specialist inspector and I participated in the Environment Agency lead inspection of Sellafield Limited’s decision-making approach [42]. The purpose of the Agency’s inspection was to assess and advise on the effectiveness of the company’s approach to decision making based on an optioneering process to determine the BAT to prevent and minimise ongoing leakage and hence enable an appropriate response to improvement requirement S1.2.13.
3. The Environment Agency did not find any non-compliance during the inspection and subsequent assessment. However, the Agency made one recommendation for potential improvement to minimise the possibility of non-compliance in the future, which they have progressed with the company. Overall, I considered that Sellafield Limited has provided adequate evidence that it used an appropriate management system for in-silo and in-ground optioneering decision-making [43].
4. Transferring progressing leak mitigation/prevention options to the MSSS programme reflects the longer-term nature of the tasks. ONR currently intends to maintain regulatory oversight of these tasks as part of future permissioning associated with MSSS retrievals activities. Should Sellafield Limited decide to implement leak mitigation/prevention options ONR would consider whether the addition of further regulatory hold points was appropriate. Similarly, should the company decide not to implement options there may be a need for them to be appropriately justified for permissioning future MSSS retrievals activities.
5. Sellafield Limited introduced the sub-programme transition arrangements, which included consideration of periodic review of leak mitigation and monitoring [44]. The second part of action 6 relates to ensuring Sellafield Limited has adequate arrangements to periodically review leak mitigation options. The MSSS retrievals programme will be progressing the sub-programme’s outputs.
6. The sub-programme transition presentation and associated discussions provided me with confidence that Sellafield Limited should be able to effectively transition the MSSS OB sub-programme into the MSSS programme [28]. Also, the company is instituting a leakage-focused oversight and advisory function and strengthening GERM oversight of leakage. I consider this is important in progressing leakage mitigation/enhanced detection options, and for periodic review thereof.
7. In forming my opinion on the adequacy Sellafield Limited’s response to issue 8145 action 6 I have taken account of the evidence gained on action 6 through focused engagements, advice from ONR C&SE, and NLR advice pertaining to actions 3 and 5. I consider Sellafield Limited has provided a suitable response to action 6 to justify closure.
8. I reviewed Sellafield Limited’s responses to issue 8145 action 1 [14] [15], which I consider is the issue’s unifying action. Closing action 1 requires the remaining nine actions to be closed. ONR’s assessments of Sellafield Limited’s responses to issue 8145 actions 2- 10 supported closure of the actions outright or by utilising appropriate tools to maintain regulatory oversight on the apparent shortfalls.
9. Overall, I consider Sellafield Limited has provided sufficient evidence to support the claim that the risks associated with the post 2019 MSSS OB leakage are reduced ALARP. As such I am content that issue 8145 action 1 can be closed.
   1. Nuclear liabilities Regulation (NLR)
10. ONR’s Nuclear Liabilities Regulation (NLR) specialist inspectors provided me with advice on the adequacy of Sellafield Limited’s management of the OB leakage to ground. Their work focused on modelling of in-ground activity migration, in-ground monitoring/sampling, the company’s assessment of monitoring/sampling and consideration of appropriate leak minimisation/mitigation.
11. NLR specialist inspectors have undertaken two major assessments [45] [46] of Sellafield Limited’s management of the MSSS OB leakage to ground. The first assessment commenced prior to the 2019 increased liquor loss rate and focused on the adequacy of the company’s MSSS leak management plan. The assessment was commissioned as part of ONR’s permissioning activities for start of MBGW retrievals from C10.
12. The second NLR assessment [46] was commissioned to inform this regulatory position statement. The assessment focused on the implementation of the MSSS leak management plan, specifically enhanced in-ground monitoring and detection, and the findings thereof against expectations.
    * 1. NLR assessment of the MSSS OB leak management plan
13. The NLR specialist inspector’s assessment [45] of the management of potential leak to ground during MSSS retrievals focussed on the adequacy of Sellafield Limited’s claims and capability in respect of delivering the following aspects of its leak to ground risk management plan:

* In-ground characterisation, monitoring and assessment.
* Analysis and decision making to ensure appropriate response.
* Arrangements enabling appropriate leak minimisation / mitigation.

1. Judging these aspects required regulatory assessment and consideration of the following:

* Maturity of the company’s conceptual site model, understanding of the ground conditions and behaviour of key contaminants, and in-ground monitoring capability.
* Sellafield Limited’s arrangements governing leak response, including performance of the GERM in discharging its remit for critical analysis of containment performance and in-ground monitoring data to advise the MSSS Operations Board regarding leak response.
* Sellafield Limited’s assessment of mitigation technologies and arrangements to facilitate deployment at an appropriate point in time and space. ONR also considered on-plant leak mitigation activities that could reduce the consequences of a leak which should be explored by the company.

1. The inspector considers Sellafield Limited has a mature understanding of the ground conditions, groundwater flow patterns, and behaviour of in-ground radioactive contamination across the site. This has been developed over many years through on-going monitoring programmes, site characterisation and scientific research. The company maintains its understanding of the conceptual site model (CSM) under review to ensure it remains valid and up to date. Additional to this and in response to the current leak, the company plans to undertake more comprehensive review of the CSM and supporting models to incorporate developments in understanding and additional data derived from, for example the Moorside site investigation. The inspector considers that the CSM forms an adequate and substantiated basis for Sellafield Limited to assess the consequences of a leak from MSSS and inform leak response decisions.
2. In reaching this conclusion, Sellafield Limited’s claim that the majority of the activity leaking to ground will remain close to MSSS, with a slow migration rate was considered and the inspector was satisfied that the capacity of the remaining sorption sites have sufficient capacity in the geosphere such that it won’t become saturated even under very high leak rate scenarios.
3. The inspector judged that the company has an adequate array of in-ground gamma monitoring blind tubes around the OB. The company committed to implementing an enhanced monitoring schedule to develop its knowledge and underpin comparison between in-ground contamination behaviour and the conceptual model understanding. The inspector also judges that the company has adequate capability for in-ground gamma dose rate monitoring to support its leak mitigation decision making, pending a decision regarding equipment resilience. The latter point was included in the OBSP activities.
4. Sellafield Limited has a mature capability regarding groundwater monitoring and appropriately targets use of its extensive network to provide the necessary data to underpin decisions regarding existing in-ground contamination and any additional contamination that may potentially arise from retrieval operations at MSSS.
5. The inspector was satisfied that from a leak to ground perspective, the consequences of the ‘very large’ leak rate scenario have been adequately modelled and demonstrated to be of low significance when considered against the legacy contamination. However, a leak rate above the peak leak rate observed in the 1970s would indicate that the leak mechanism is not solely due to the reopening of historic crack(s), and other mechanisms could be undermining containment performance with potentially significant consequences.
6. Sellafield Limited has provided sufficient evidence to support its claim that even at ‘very high’ leak rates, the risk of off-site contamination transport is limited, with several decades until peak concentrations are reached.
7. The inspector raised a level three regulatory issue, issue 8660, requiring Sellafield Limited to address seven recommendations arising from the assessment. Four of the recommendations are linked to issue 8145 actions. The other recommendations require the company to:

* Review and justify the leak rate threshold within loss of containment investigation principle 2.
* Update the GERM Terms of Reference to formalise regular attendance by a member of its Independent Land Quality Peer Review Panel.
* Elevate the GERM to a status analogous to that of an MSC and clearly demonstrate application of a challenging mind-set to data analysis ensuring clear and robust understanding of leak behaviour/consequences informing the company’s decision-making regarding leak response.

1. Overall, the inspector judged Sellafield Limited had adequately demonstrated arrangements for management of a leak to ground from MSSS. This included control and mitigation of the consequences such that the risks arising from ground contamination are managed to be ALARP, and that continued retrieval of the waste stored in MSSS should remain Sellafield Limited’s priority.
   * 1. NLR assessment of the implementation of the MSSS leak to ground management plan
2. The second NLR assessment [46] focused on the NLR- aspects of implementation of the leak management plan. The assessment considered Sellafield Limited’s responses to issue 8145 actions 3 and 5, and level three issue 8660 actions, which are concerned with the mitigation response plans for the migration pathways.
3. The inspector focused on the following areas:

* Understanding of the potential migration pathways and leaks from MSSS.
* In-ground mitigation measures.
* Ongoing monitoring of the OB leakage.

1. ONR’s expectation is for licensees to understand the land quality and contamination characteristics of the site to inform decisions on land quality management. The extent of site characterisation (including characterisation of any contaminants) should be sufficient to understand the potential and existing sources of contamination, pathways and receptors. The site characterisation should be used to establish a conceptual site model (CSM) which includes the pathways by which contamination from a source could reach potential receptors and set out the baseline conditions against which subsequent changes can be reviewed.
2. Sellafield Ltd has developed a CSM to represent the current understanding of the leak characteristics and contaminant distribution/behaviour in the sub-surface, in line with regulatory expectations. Sellafield Ltd uses the CSM to underpin the design of the enhanced monitoring programme, the interpretation of monitoring results, modelling and overall risk assessment.
3. ONR expects the CSM to describe the pathways to receptors and the potential risks posed by the contaminated land and groundwater. The inspector considered Sellafield Limited responded proactively to the groundwater monitoring data and acknowledged that there is migration of contamination in the Calder Pathway. The inspector considered there is still significant uncertainty in the understanding of the migration of contamination in this area of site.
4. The inspector considered that Sellafield Limited has provided sufficient evidence that it is continually reviewing its understanding of the MSSS OB leak characteristics and contaminant behaviour in the ground and groundwater on site. The company has updated the CSM to ensure it reflects current understanding in line with regulatory expectations. This includes considering n the Calder Pathway contamination plume. The inspector noted that Sellafield Limited has prioritised in-ground leak mitigation measures on the Calder Pathway in the forward plans on environmental considerations.
5. With regard to leak mitigation / prevention, ONR expects decisions on land quality management be informed by an assessment of options for remediation that exist for each land and groundwater contamination source term and take account of the overall remediation strategy for the site. The Sellafield site CSM currently does not include consideration of the Calder Pathway. In the absence of detailed modelling and assessment of the contaminant migration in the Calder Pathway, Sellafield Limited developed a scoping risk assessment model for the Calder Pathway to support the optioneering process.
6. The inspector questioned Sellafield Limited about how the amount (volume and activity levels) of contamination in the ground and groundwater, including that from the historic leak, changes with the various mitigation options that have been identified and what impact this will have on the site end state. The inspector was satisfied with the company’s response. Based on this response, the inspector considered that the forward plan for the implementation of mitigation measures will inform Sellafield Limited’s understanding of the nature and volume of wastes generated from implementing the mitigation measures. This is expected to give ONR confidence that regulatory expectations will be met.
7. Issue 8145 action 3 requires Sellafield Limited to identify outline mitigation response plans for each pathway. At present, Sellafield Limited has not identified outline mitigation response plans for the Main Gate and Buried Channel Pathways, which the inspector considers should be included in the forward programme of work. ONR’s expectation is that Sellafield Limited’s MSSS OB leakage forward plans will consider mitigation options for these pathways. The inspector added a new action to issue 8660 to capture the recommendation.
8. The inspector noted that the NLR assessment of the MSSS leak management plan considered the adequacy of the in-ground monitoring arrangements (blind tubes and boreholes). The inspector therefore focused on the adequacy of the enhanced monitoring regime to inform characterisation of activity migration against expectations.
9. The enhanced monitoring regime monitors migration of mobile species from the post-2019 leakage and slow-migrating species from the original and post-2019 leakage. The enhanced monitoring regime entails more frequent blind tube monitoring which helps identifying changes in activity (attributed to activity migration). Boreholes are also sampled more frequently, and the species analysed is greater. The enhanced monitoring findings are subject to appropriate analysis and oversight.
10. The inspector judged Sellafield Ltd provided sufficient evidence of the successful implementation of the enhanced monitoring regime for in-ground gamma (blind tube) monitoring. The company has appropriate oversight and reporting of the monitoring results and emerging trends such that its understanding of the leak can be kept up to date in line with regulatory expectations. The inspector was satisfied that Sellafield Limited has arrangements in place utilising GERM to periodically review the concern levels of blind tubes to ensure that the targeted monthly blind tube measurements are appropriate.
11. The inspector was satisfied that Sellafield Limited is appropriately targeting environmentally mobile radionuclides to identify migration of contamination associated with the current leak via the groundwater monitoring network. The inspector considered the enhanced monitoring of the borehole array closest to MSSS provides Sellafield Limited with sufficient data to identify increases in radionuclides that require further investigation.
12. Based on the evidence sampled, the inspector was confident that the current enhanced monitoring programme is sufficient to support the ongoing management of the OB leak. The inspector judged Sellafield Limited has provided sufficient evidence to demonstrate that it has effective arrangements in place to evaluate and respond to the outputs of the blind tube and groundwater monitoring so that this may inform decision making on the leak response.
13. Overall, the inspector judged that Sellafield Limited provided sufficient evidence to justify closing issue 8145 action 5. The inspector considered issue 8145 action 3 had not been fully addressed. The inspector made four recommendations for, which are expected to be addressed by Sellafield Limited’s MSSS leak forward programme of work.:

* Recommendation 1: Sellafield Limited’s forward programme for the implementation of in-ground mitigation measures should include updates to the CSM and the associated assessment of contaminated land volumes to reflect migration of contamination in the Calder Pathway.
* Recommendation 2: Sellafield Limited should review the outputs of the ‘Should We…?’ process once the CSM has been updated to include the Calder Pathway to confirm that the proposed mitigation measures to be taken forward will deliver an overall benefit.
* Recommendation 3: Sellafield Limited should review the outputs of the ‘Should We…?’ process once the new site end state strategy is developed to confirm that the proposed mitigation measures to be taken forward are still compatible with the desired end states.
* Recommendation 4: Sellafield Limited’s forward programme for the implementation of in-ground mitigation measures should consider the options for mitigating migration of contamination in the Main Gate and Buried Channel Pathways or provide an appropriate justification as to why this is not required at this time.

1. The recommendations were shared with Sellafield Limited [47]. The company’s initial views were that the recommendations can be addressed by planned work that will be delivered by the remediation value stream land quality team. The work is expected to take several years to deliver, and the company will provide ONR will the delivery plan soon. The inspector will continue to engage with Sellafield Limited as part of routine engagements on MSSS retrievals.
2. The inspector was content that regulatory oversight of the recommendations can be maintained by adding a new action to issue 8660. The inspector judged that from the NLR perspective issue 8145 action 3 could be closed.
   1. Civil and structural engineering (C&SE)
3. The ONR civil and structural engineering (C&SE) specialist inspector provided advice on the adequacy of Sellafield Limited’s assessment of the effect of leakage on the OB civil structural integrity, and MSSS civil structure ageing management. The former included consideration of leakage greatly exceeding rates observed to date.
4. The inspector undertook two assessments [48] [49] of the civil and structural aspects of MSSS OB leakage management. The first major assessment focused on responses to issue 8145 actions 8 and 9. The two actions focused on C&SE OB structural integrity to gross leakage to ground and ageing management.
5. The second, supplementary, assessment considered the additional work undertaken by Sellafield Limited regarding issue 8145 actions 8 and 9, and the C&SE aspects of actions 2, 6 and 7.
6. The C&SE specialist inspector’s major assessment focused on the adequacy of Sellafield Limited’s responses to issue 8145 actions 8 and 9; these being primarily concerned with C&SE aspects of MSSS OB leakage. The action responses were also aligned with C&SE-relevant claims in the MSSS leak to ground management plan. These being:

* Claim 1.1: Mechanisms for initiating a leak from containment have been assessed and are understood.
* 1.1.1 Only a through-building crack could lead to the loss of containment, and it is not considered credible that new through-thickness cracks would arise in any part of MSSS.
* 1.1.2 The only credible leak source is the re-opening of below-ground historic cracks in the original silo compartments.
* 1.1.3 Historic through-building cracks in the OB below ground are considered to have self-sealed. Any leakage from historic cracks is likely to be a seepage.
* 1.1.4 An above-ground leak from a through-building crack in the primary containment of the OB or first, second or third extensions due to loadings associated with waste retrievals operations is not considered credible.
* Claim 3.1: All reasonably practicable enhancements have been made to the silo structure to account for SEP machine operational loadings.

1. ONR previously assessed [50] the civil engineering and external hazards aspects of Sellafield Limited’s proposal for initial waste retrievals from MSSS. The findings of the assessment informed the ONR decision to grant permission for Sellafield Limited to commence retrieving MBGW from FE compartment 10. The assessment conclusions included the judgement that the company had adequately demonstrated understanding of the short-term increase in risk created by retrievals from C10 and had taken appropriate civil engineering actions to mitigate the risks.
2. Action 8 requires Sellafield Limited to demonstrate that it has adequately assessed the structural integrity of the OB civils structure to high liquor loss rates. The inspector focused on the following topics:

* Correlation of current leakage rates with structural cracking.
* Scour effects (soil erosion resulting from leakage flow).
* Structural margins, effects of increased levels of cracking and potential for cliff-edge effects (structural withstand to gross liquor loss).
* Risk of increased leakage rate due to corrosion of steel reinforcement within the concrete containment structure.
* Risk of steel reinforcement corrosion from the external environment.
* Risk to structural safety functions due to corrosion of steel reinforcement.
* Degradation of polyvinyl chloride waterbars at concrete containment construction joints.

1. For correlation of current leakage rates with structural cracking, the inspector was satisfied that Sellafield Limited had adequately correlated postulated levels of cracking in the silo structure with observed leakage rates. The company’s assessment considered both above-ground and below-ground cracks. The inspector considered this appropriate, as although there are no confirmed above-ground current leakage locations, significant portions of the walls cannot readily be viewed and therefore above-ground leakage cannot be ruled out.
2. Modelling above-ground cracking eliminated uncertainties associated with soil-induced flow retardation, providing better insight into crack morphology on liquor flow rates. The inspector was satisfied that Sellafield Limited’s approach was reasonable and provided sufficient information to meet regulatory expectations.
3. The inspector agreed that the predicted rates of leakage through credible above-ground cracks appeared consistent with the currently observed leakage rate. For example, an illustrative above-ground leakage rate of 2m3/day could be achieved with a 0.3mm wide 0.6-2 metre long through-thickness crack. The sub-programme outputs addressed this finding including development of methods for inspecting obscured areas of OB primary containment (for example, behind shield walls) and MSSS voids for indications of deterioration and leakage.
4. Soil scouring could further increase leakage rates and possibly challenge civil structural stability. The inspector was satisfied with the evidence supporting Sellafield Limited’s view that scouring on MSSS was unlikely.
5. For structural margins, the inspector was satisfied that Sellafield Limited had appropriate evidence to support the conclusion the OB civil structure was robust to very large increases in below-ground leakage rates. The inspector was also satisfied with the company’s argument that formation of new through-thickness cracks is reasonably low.
6. Corrosion of reinforcing steel is a credible degradation mechanism that might affect structural design margins, increase the leakage rate from existing cracks or generate new cracks. Sellafield Limited identified two mechanisms for steel reinforcement corrosion, corrosion by silo liquor and external-environment-induced corrosion.
7. The inspector judged that the company had provided sufficient evidence to support the claim that if reinforcement corrosion did occur on either face of the structure, it would be unlikely to lead to new through-thickness cracks and hence to an increased leakage rate. The risk that reinforcement corrosion on the inside face of the structure will increase leakage at existing cracks is judged to be low, though it remains credible that significant spalling could lead to the dislodging of material currently blocking a crack.
8. The inspector agreed with the company that the greatest risk of reinforcement corrosion from the external environment is due to carbonation, which has been demonstrated to be an active degradation mechanism. The risk of generalised corrosion from external chloride ingress is low, though localised corrosion at defects or highly carbonated areas is more likely. This point is covered further as part of assessing the response to action 9. ONR will maintain oversight of Sellafield Limited’s management of carbonation on MSSS OB through routine engagements and inspections.
9. Waterbars are strip-like elements embedded in civil structure construction joints during construction. Their function is to prevent leakage through the joint. In MSSS OB, the waterbars were manufactured from polyvinyl chloride (PVC) plastic. It is not possible to determine if the waterbars were fitted correctly during construction or to inspect them in-service.
10. Sellafield Limited’s assessment of waterbar in-service degradation concluded that it is difficult to estimate the extent to which degradation mechanisms are likely to have affected the performance of the waterbars, or to predict their remaining serviceable life. This conclusion is the result of the uncertainty surrounding many variables that might affect the amount and rate of degradation.
11. The inspector agreed with Sellafield Limited’s overall conclusion that gross physical failure of waterbars is unlikely to be the primary initiator of renewed leakage. For gross physical failure, there would need to be significant movements in combination with widespread embrittlement, and there is no evidence to suggest that there have been recent movements. The inspector considered it more likely that liquor has gained renewed access to areas of waterbar that were damaged during construction. It is credible that this access could have been obtained by wash-out of material from pre-existing cracks.
12. The inspector sampled the adequacy of Sellafield Limited’s consideration of cliff-edge effects within their assessment of MSSS OB civil structural stability. The inspector:

* was content that the most significant risk concerns the internal walls, which are essential to the stability of the outer walls. The inspector judged that an adequate margin has been demonstrated for the current quiescent loading and also for a seven-metre differential in liquor loading between adjacent compartments, which is a load case that is beyond the design basis event.
* was satisfied, based on the evidence presented, that the risk of a cliff-edge effect due to increased leakage, or the forming of credible new through-thickness cracks, is acceptably low.
* was content, despite the uncertainties regarding concrete strength, that the calculations make a number of conservative assumptions and considered that the company had demonstrated that the outer walls of the OB silo are adequately robust, and not vulnerable to cliff-edge effects during normal operations.
* was satisfied that Sellafield Limited’s assessment showed that the structure is tolerant to gross liquor loss, with no cliff-edge effects, even if the leakage rate was increased by an order of magnitude. The structure is also tolerant to beyond design basis losses in liquor level in any one compartment, with bulk containment and global stability being maintained.

1. The inspector sampled Sellafield Limited’s substantiation of adequate margin with no cliff-edge effects for MSSS OB reinforced concrete structure, provided the steel reinforcement is not significantly corroded. The inspector judged that the evidence does not currently support a need to reduce section capacities due to reinforcement corrosion, or concrete spalling. The inspector therefore focused on the adequacy of the company’s management and control of OB reinforced concrete corrosion.
2. The inspector judged that the company had undertaken an adequate assessment of the structural integrity of the civil structure. The inspector was satisfied that this assessment showed that the structure was tolerant to gross liquor loss, with no cliff-edge effects, even if the leakage rate was increased by an order of magnitude. The structure is also tolerant to beyond design basis losses in liquor level in any one compartment, with bulk containment and global stability being maintained.
3. The inspector agreed with the company that above ground leakage sources cannot be discounted. The inspector agreed that further investigation should be carried out to determine, where reasonably practicable, whether leakage exists in areas that are currently not exposed to view. This was explored further as part of Action 9.
4. Overall, the inspector judged that Sellafield Limited had provided sufficient evidence to justify closing issue 8145 action 8.
5. Action 9 concerns the adequacy of Sellafield Limited’s ageing management arrangements, and their implementation for OB reinforced concrete containment. Sellafield Limited’s MSSS concrete health management strategy identified carbonation and chloride ingress as the most significant degradation mechanism from the external environment. The inspector agreed with this view.
6. The inspector sampled the company’s management of carbonation/chloride ingress on MSSS OB. From the evidence sampled on MSSS OB civil structure concrete ageing management, the inspector identified that:

* Sellafield Limited had generally followed the principles of the relevant British Standard (BS 1504-9 in terms of assessing the current condition of the concrete prior to specifying repairs.
* Material periodic testing has been undertaken following relevant good practice [42] and that the use of periodic testing meets the expectations of relevant ONR guidance.
* Sellafield Limited’s optioneering study to manage concrete ageing recommended application of decorative coating (later deleted partly due to having to control operator’s radiation exposures) and, if necessary, corrosion inhibitor. The company incorporated application of the corrosion inhibitor during concrete repairs to accessible areas of the OB exterior surfaces. Undertaking repairs and inhibitor application was hampered as working was often in high radiation areas, with the associated controls on operator exposure.

1. The inspector recommended (recommendation 1) that the MSSS concrete health management strategy and any associated ageing and degradation models should be reviewed and updated.
2. The inspector focused on Sellafield Limited’s use of corrosion inhibitor as part of managing MSSS OB civil structure ageing. The inspector considered that the use of a corrosion inhibitor is a permitted method of corrosion protection in accordance with Principle 11 - Control of anodic areas, of the relevant British Standard, BS EN 1504-9. The proposed product also claims to provide cathodic control (Principle 9 of the Standard). There is currently no standard for inhibitors, so the inspector considered that evidence of the effectiveness of any such product should be obtained before specifying its use.
3. Advice the company obtained from the manufacturer of the corrosion inhibitor was that it will not slow the advance of the carbonation front. The success of the product will therefore depend on an adequate passive film forming on the reinforcement to protect it from corrosion due to carbonation or chloride mechanisms. Whilst there is the option to apply a carbonation resistant coating after the application of the corrosion inhibitor, the inspector accepted that there may be arguments against doing so, such as dose uptake to the workforce or that the coating might impede the further application of corrosion inhibitor, should this be necessary.
4. Overall, the inspector judged that if the application of a corrosion inhibitor was the sole proposed means of protecting the reinforcement from corrosion, then an adequate long-term monitoring regime should be adopted to assess the performance of the product in arresting corrosion and the onset of further degradation. The inspector raised C&SE recommendation 2 on this point.
5. The inspector identified that the area of OB north wall behind the shield wall was not subject to routine inspection nor was corrosion inhibitor planned to be applied. The shield, which is very close to the OB wall was erected to provide external radiation shielding for workers. The inspector raised C&SE recommendation 1 on this point.
6. In the supplementary assessment [49], the inspector focused on Sellafield Limited’s responses to the three recommendations against issue 8145 action 9 arising from the C&SE major assessment [48] and the C&SE aspects of actions 2,6 and 7. The latter three actions are multi-disciplinary nature requiring assessment from several specialists within ONR.
7. In-ground leak mitigation options (action 6) identified by Sellafield Limited are divided into “near silo” technologies and “away from silo” technologies. A number of these options are of relevance to civil engineering, particularly any near silo options that could disturb the ground or alter the water table in a manner that might lead to settlement.
8. Near silo technologies need to take account of the risk that they could cause an alternative leak path to ground level, with significant radiological consequences. The inspector was satisfied that an appropriate civil engineering specialist was present at the workshops so that structural issues or concerns could be identified and considered, in addition to appropriate opportunities being identified.
9. Sellafield Limited is addressing action 7, retrieval choreography, in the in-plant leak mitigation considerations. Retrieval choreography is expected to be routinely reviewed for the duration of retrievals. The inspector judged adequate consideration had been given to the OB and FE structural implications of choreography changes.
10. In relation to action 2, the inspector agreed with Sellafield Limited that the most plausible location for a leak was existing cracks in the walls below ground. These through-thickness cracks are highly likely to have been initiated by historic thermal excursions. In using the term ‘crack’, the inspector considered this included construction joints, which form a plane of weakness in the wall. Although these joints include a ‘waterbar’, there is evidence that in several locations these features have not prevented historic liquor loss, indicating that some may have been improperly constructed.
11. When considering the company’s response to action 2, the inspector took account of the potential for above-ground leakage. In particular, the OB north wall damp patch and south void possible leakage. The latter is currently still being investigated by the company, with continued oversight by ONR.
12. The inspector was content that Sellafield Limited had addressed to the recommendation for reviewing and updating the MSSS concrete health management strategy and any associated ageing and degradation models.
13. The inspector was content that the recommendation regarding the development of options to inspect above-ground areas that have not been inspected since the leak developed is being progressed by the company. The inspector would monitor progress of the planned inspections as part of normal regulatory business. The inspector will progress with Sellafield Limited the two remaining recommendations via appropriate regulatory tools, such as advice and guidance and regulatory issues.

* C&SE recommendation 1: Sellafield Limited should evaluate ALARP options to quantify, prevent, minimise, mitigate or remediate the consequences of the leak into the south void, including giving due consideration to the implications should the leak worsen.
* C&SE recommendation 2: Sellafield Limited should consider the reasonable practicability of determining, by established corrosion monitoring techniques, the effectiveness of the application of a corrosion inhibitor to the OB concrete surfaces.

1. The recommendations were shared with Sellafield Limited [47]. The company’s initial views were that the recommendations can be addressed by planned work in progress, with some extension in scope for recommendation 1. The inspector will continue to engage with Sellafield Limited as part of routine engagements on MSSS retrievals, with recommendation 1 captured in a level 4 regulatory issue and recommendation 2 given as advice and guidance.
2. Overall, the inspector considered that Sellafield Limited’s responses to the three recommendations, and responses where sufficient to close issue 8145 action 9. The inspector judged that, from a civil engineering perspective, issue 8145 actions 2, 6, 7 can be closed.
   1. Chemical engineering and Chemistry
3. The ONR chemical engineering and chemistry specialist inspectors provided advice on the adequacy of Sellafield Limited’s assessment of the chemical engineering/chemistry aspects of the OB leakage. This involved interactions between the water added to the compartments (top up water and SEP cave wash water), the waste (mainly Magnox swarf and associated corrosion products) and the civil structure (both the bulk structure and the postulated leakage location(s). Interactions with the waste determine the chemical and radiochemical composition of the leaking liquor.
4. The ONR SDFW chemical engineering specialism lead provided Sellafield Limited, jointly with the Environment Agency, regulatory advice [51] for the company to consider when evaluating the option of damp/dry storing MSSS OB waste. The company has taken cognisance of the regulatory advice in the MSSS OB leakage sub-programme work activities.
5. The inspector was supported by a chemistry specialist inspector. Their assessment [52] focused on Sellafield Limited’s responses to issue 8145 actions 2, 5 and 7. The topic areas assessed were:

* MSSS OB silo liquor chemistry in the quiescent storage state.
* Probable sources, leak path(s) from MSSS OB and consequences in the quiescent storage state. This topic area included consideration of:
* Below-ground leakage and the associated consequences.
* MSSS OB leak above-ground radionuclide inventory.
* Above-ground leakage path(s) and the associated consequences.
* Design extension conditions and leakage mitigation. Design extension conditions relates to consideration of leakage beyond the safety case current operational envelope. Leak mitigation relates to the chemical engineering/chemistry aspects of Sellafield Limited’s proposals thereof.

1. The inspectors judged that Sellafield Limited had undertaken a significant programme of work to understand the MSSS OB silo liquor chemistry and potential leak path(s) to ground. The work on silo liquor chemistry was particularly complex with a high degree of associated uncertainties because it relied heavily on modelling interactions between top up water, cover liquor and complex, heterogeneous waste.
2. Sampling cover liquor is challenging by virtue of very limited sampling points and needing significant protective shielding when handling samples. It is not possible to sample liquor at the point(s) of leakage because these are likely to be at the base-slab-level in radioactive soils and their location(s) have not been identified with the requisite accuracy. The benefits of sampling liquors need to be balanced against limiting operator radioactive exposure.
3. For action 2, the inspectors acknowledged the complexity of the chemical behaviour of the MSSS OB silo liquor, and the constraints associated with the verification and validation of the modelling. They consider that Sellafield Limited has made great efforts to understand and model the chemistry drawing together a better understanding of the material within the OB, how it behaves and the nature of the radioactive leakage and escape.
4. However, the inspector is of the opinion that the MSSS leak planned forward work will be expected to further improve Sellafield Limited’s understanding of leaking liquor chemistry. In addition, the inspector judged there to be a need for some regulatory intervention and guidance, with chemistry and chemical engineering technical issues being raised. The areas have been captured in sixteen recommendations to be taken forward via the provision of regulatory advice or ONR regulatory issues, as appropriate.
5. For action 5, the inspectors considered that Sellafield Limited had presented several characterisation and monitoring techniques for the MSSS OB leakage. However, their assessment identified technical issues related to the monitoring and characterisation of the MSSS OB leakage above-ground and real-time monitoring of leakage from the MSSS OB including the minimisation of dose uptake and the capability to improve the speed of response. These shortfalls require regulatory follow-up. The shortfalls were captured in two recommendations.
6. For action 7, the inspectors judged that, from a chemical engineering /chemistry perspective, Sellafield Limited had appropriately considered the choreography of waste retrievals for the MSSS inventory of Compartments 1 to 22. This was regarding improving the pace of retrievals within the OB and reducing the time at risk related to the existing leakage. The inspectors identified technical issues that require regulatory follow-up. These relate to Sellafield Limited’s articulation of the understanding of the impact of the MSSS OB waste retrieval programme on its current hazard management strategies for the MSSS OB leakage. These points have been captured in three recommendations.
7. Based on the evidence sampled as part of this assessment, the inspectors identified several shortfalls in the responses to issue 8145 actions 2,5 and 7. The sixteen resultant recommendations are summarised below. The high number reflects the complexity of the work in responding to action 2.

The 16 recommendations arising from the inspectors’ assessment are as follows:

* Recommendation 1: Sellafield Limited should review the original building liquor sampling process and frequency to improve, as far as is reasonably practicable, the quality of the liquor composition dataset and the understanding of the behaviour of the liquor in response to building activities. The review should consider all relevant aspects including liquor representation, sampling frequency and worker dose uptake. All improvements identified should be in place in sufficient time to prepare an adequate baseline to compare the effects of the retrievals on the silo liquor composition.
* Recommendation 2: Sellafield Limited should provide evidence to support its claim that the cover liquor data set reference values (species concentration) are representative and include adequate conservatisms. Sellafield Limited should apply the bounding cases (the maximum and minimum) cover liquor data set reference values (species concentration) and confirm what impact, if any, this would have on the leak liquor composition (LTG tool) and consequence assessment.
* Recommendation 3: Sellafield Limited to provide further evidence to support its claim that the cover liquor data set is representative of the mixed waste layer MBGW voidage liquor data set.
* Recommendation 4: Sellafield Limited should clarify the underpinning assumptions utilised within the computational fluid dynamic and leak to ground models, the impact that non-equilibrium conditions may have on behaviour within the OB. This non-equilibrium behaviour should include rates to achieve equilibrium for both active and non-active components as well as the impact of key minerals in Wastwater on the system pore liquor does not exchange with the bulk silo fluid.
* Recommendation 5: Sellafield Limited should make it clear whether the hydrogen currently being detected in the OB ventilation flow is gradual release of trapped hydrogen or that produced from ongoing corrosion of unreacted silo contents as liquor percolates through to the sludge bed centre.
* Recommendation 6: Sellafield Limited should acknowledge that MSSS OB is leaking from a number of sites, rather than the leak site referenced in the safety case. Sellafield Limited should consider the location of the leak(s) and determine the liquor lost via each leak source to determine what impact this has on its hazard management strategy should the leak rate increase at any given leak site.
* Recommendation 7: Sellafield Limited should provide further evidence to support the initiation of the opening of an existing leak path via erosion and the conditions around the original building when the original leakage rate fell below the limit of detection.
* Recommendation 8: Sellafield Limited to further consider the impact of demineralised water (DMW) via the EWTU system on the MSSS silo liquor chemistry and waste solids in addition to the current evidence presented regarding concrete surfaces of the Silos. Sellafield Limited should focus the work on the potential for dissolution of sludge at the leak site(s) upon interaction with a low mineralised cover liquor composition (changed due to of DMW additions). Including the consideration of bimetallic transition group compounds.
* Recommendation 9: Sellafield Limited should put in place the ability to deliver a near real time monitoring system of OB leakage. This should be in place substantially prior to retrievals commencing within the original building to ensure a baseline and experience can be acquired. It should aim to provide a timely oversight of the changes to the OB leak rate especially where DMW additions occur and where the building activities are detected on the building movement monitoring system.
* Recommendation 10: Sellafield Limited to provide further evidence to support its leakage to ground modelling assumption that the cover liquor does not interact with the waste bed and thus represents the main source for the loss to ground. Related, Sellafield Limited to predict the activity lost to ground if the cover liquor interacts with the waste bed.
* Recommendation 11: Sellafield Limited to determine how the addition of DMW has changed the liquor data set for the cover liquor. Sellafield Limited to confirm what impact, if any, this has on the predicted activity released to ground from MSSS OB leakage (LTG tool).
* Recommendation 12: Sellafield Limited should develop a robust monitoring and characterisation programme for the MSSS OB above ground leakage to establish and monitor the current above ground leakage for all faces of the OB. The programme should interface with the below ground leakage monitoring and include technical oversight that can identify any behaviour that indicates the OB is moving towards a higher leakage rate above ground. This should be in place as soon as is reasonably practicable.
* Recommendation 13: Sellafield Limited should confirm the cumulative MSSS OB liquor loss from unenclosed (i.e., those above ground or into the voids) leak path(s) and predict the activity released. This information should be used to inform the radiological consequences of a leak above ground during quiescent and operational states and the mitigation response.
* Recommendation 14: Sellafield Limited should demonstrate an adequate understanding of the potential impact of the MSSS waste retrieval operations on the MSSS OB silo liquor chemistry, the leak(s) rate(s) and sources of leak (above and below ground). Sellafield Limited should confirm if the plant and environmental monitoring regime remains adequate to detect changes in a timely manner. This information should inform Sellafield Limited’s claims on the consequence of MSSS OB silo liquor leakage during retrievals.
* Recommendation 15: Sellafield Limited should:
* Demonstrate an adequate understanding of the potential impact of design extension conditions on the MSSS OB silo liquor chemistry and silo behaviour, including leakage paths.
* Confirm if the plant and environmental monitoring regime remains adequate to detect changes at design extension conditions in a timely manner
* Confirm that all practicable opportunities to remediate or repair the outside of all above ground primary containment surfaces of the OB using modern technology. This also applies to the north and south voids.

This information should inform Sellafield Limited’s claims on the consequence of MSSS OB silo liquor leakage during retrievals.

* Recommendation 16: Sellafield Ltd should examine the overarching choreography of retrievals within MSSS to identify opportunities for the earliest reasonably practicable retrieval of the MBGW within the south and north voids. This is with a view to ensuring all leak paths from the OB, in particular, are exposed, seepage and pooling of liquid can be detected within the voids and methods for reducing or preventing seepage through the walls of C6 and C5 can be considered.

1. The recommendations were shared with Sellafield Limited [47]. The company’s initial views were that the recommendations can be addressed by planned work in progress, with some extension in scope. Most work is planned to be completed in 2023. Work associated with recommendation 16 and the third part of recommendation 15 is expected to take several years to complete. The inspectors will continue to engage with Sellafield Limited as part of routine engagements on MSSS retrievals.
2. Overall, the inspectors judged that, from the chemical engineering and chemistry perspective, issue 8145 actions 2, 5 and 7 could be closed. The shortfalls identified in their assessments were captured in sixteen recommendations. The inspectors will progress the recommendations with Sellafield Limited via the appropriate regulatory tools, such as advice and guidance or regulatory issues at the appropriate level (below level 2).
   1. Radiological protection
3. The ONR radiological protection (RP) specialist inspector provided advice on the adequacy of Sellafield Limited’s assessment of the radiological impact of the OB leakage on workers on the site and members of the public off site.
4. The inspector’s assessment [53] [54] focused on Sellafield Limited’s responses to issue 8145 action 4, which is concerned with the radiological safety impact of the leakage on workers on the site and members of the public off site. The RP assessment encompassed Sellafield Limited’s response to action 4, primarily the OB leakage radiological dose assessment [55] [56]. The inspector also considered the company’s response to Environment Agency issue 9, which required Sellafield Limited to address similar concerns.
5. Sellafield Limited’s dose assessment used the current leak management plan worst-case (25m3/day) scenario leakage rates. The OB leakage was assumed to continue to 2050s, the current date for completion of MSSS bulk waste retrievals. The assessment considers exposure of off-site exposed groups, and workers on site from inadvertent human intrusion (for example, excavating proximal to MSSS).
6. Sellafield Limited’s dose assessment was revised [56] to include the radioactive species’ migration pathway to the river Calder.
7. The inspector noted the RP basic consequence assessment [57] undertaken as part of ONR’s enforcement investigation into the OB leakage. The assessment focused on the adequacy of Sellafield Limited’s judgment on worst-case radiological doses for a worker and members of the public.
8. The basic consequence assessment supporting ONR’s investigation included the following statements:

* Provided that there is no physical mechanism which could result in the transfer of activity upwards towards the surface, the inspector was satisfied that there are no radiological consequences for workers currently working on the site and this will remain the case even if the leak continues at the current rate for a number of years.
* Provided that there is no “fast pathway” to allow the rapid escape of contamination off the site – and there is no evidence that there is such a pathway, I am satisfied that the release has negligible consequences for the public.

1. The inspector identified that Sellafield Limited’s radiological dose assessment concluded:

* The estimated doses to all off-site potential exposure groups from the current leak assuming worst-case scenario are less than those estimated for the historical leak from MSSS. The highest doses from the current leaks are experienced by the consumers of shellfish potential exposure group which have a peak radiological dose of 0.5 mSv y-1 in 2150 (equivalent to a peak risk of 3.0E-08 y-1).
* The results may be compared to the dose to shellfish consumers from the historical leak of 4.0 mSv y-1 in 1995.

1. The inspector sampled the following areas of the radiological dose assessment.

* Conceptual site model of the Sellafield site subsurface. The model is concerned with ground conditions, groundwater flow patterns, and behaviour of in-ground radioactive contamination across the site.
* Method for the radiological assessment of the current leak from MSSS. The method considered:
* Source (total activity leaked to ground, location, and geometry).
* Leakage radioactive species inventory.
* Transport through the unsaturated zone.
* Geosphere pathway.
* Biosphere compartment model.
* Receptors (workers on site and identified groups off site, including beach occupants, consumers of marine fish/estuary shellfish etc.).
* Model integration period.

1. The inspector accepted, from an RP perspective, the ONR NLR specialist inspector’s assessment [45] of the Sellafield site conceptual model.
2. With respect to the radiological dose assessment, the inspector was content with:

* the leakage monitoring and trending of data being undertaken, and that Sellafield Ltd would be able to detect any increased migration of activity across the site in a timely manner.
* Sellafield Limited’s dose assessment considered the appropriate public exposed groups and the exposure pathways, and they are aligned to that in the Radioactivity in Food and the Environment, 2020 (RIFE 26) report.
* Sellafield Limited’s use of a conservative radiological health risk coefficient in their assessment.
* Sellafield Limited’s consideration of a comprehensive range of receptors, and the projected dose out to 2150 remains below any current public dose exposure limits.

1. The inspector’s opinion, based on the review of the Sellafield Ltd radiological dose assessment and the assessment undertaken by the ONR NLR specialist inspector [45], Sellafield Limited had adequately addressed Regulatory Issue 8145 action 4.
2. The inspector noted and welcomed the ongoing radiological dose assessments to members of the public, and reviews of the conceptual model with respect to the current MSSS leak. Sellafield Ltd also stated that an assessment of dose to biota in the terrestrial, marine and freshwater environments will be presented in a future report.
3. Sellafield Limited updated the radiological assessment to include consideration of activity migration to the river Ehen estuary and river Calder.
4. The company’s assessment for the river Ehen estuary combined doses from the historical and current leaks of 1.3 Sv y-1 in 2095 (baseline) and 5.9 Sv y-1 in 2098 (worst case). These are below the dose constraint of 300 Sv y-1, which is a requirement stated in the Guidance on Requirements for Release from Radioactive Substances Regulation (Requirement R9 of GRR) for the period of radioactive substances regulation.
5. The combined peak doses for a 75:25 split between the river Ehen and river Calder from the historical and current leaks of 1.3 Sv y-1 in 2090 (baseline) and 7.4 Sv y-1 in 2094 (worst case) are below the dose constraint of 300 Sv y-1, which is a requirement stated in GRR for the period of radioactive substances regulation.
6. All the dose scenarios (including river Ehen estuary and river Calder) assessed by Sellafield Ltd in the revised dose assessment result in doses being below the dose constraint of 300 Sv y-1, which is a requirement stated in the Guidance on Requirements for Release from Radioactive Substances Regulation (GRR) for the period of radioactive substances regulation.
7. The worst-case dose assuming no remediation in 2120, scenario is only 2.7E+01 Sv y-1.
8. The inspector compared the modelled off-site radiological doses against Ionising Radiations Regulations 2017 (IRR17). The regulation guidance advises constraining the dose to members of the public from each source to less than 0.3 mSv per year. The legal dose limit for members of the public as stated in IRR17 is 1mSv per year.
9. The inspector was content that Sellafield Ltd had considered a comprehensive range of receptors, and the projected dose out to 2094 remains below any current public dose exposure limits. The inspector considered, based on the review of the Sellafield Limited radiological dose assessments and their assessment [45], Sellafield Limited adequately assessed the potential effects of the leak on receptors.
10. In conclusion, the inspector recommended closure of issue 8145 action 4. 
    1. Fault studies
11. The ONR fault studies (FS) specialist inspector provided advice on the adequacy of Sellafield Limited’s assessment of the potential impact of the OB leakage of a severe accident on the facility.
12. There was no explicit consideration of the OB leak during the recent review of the MSSS severe accident analysis (SAA). The MSSS SAA focussed on potential drops and spills arising from the new operations taking place as part of the commencement of retrievals, specifically large loss of above-ground containment.
13. MSSS SAA attracts a high security classification and so the FS specialist inspector’s [58] assessment does not record details of the areas sampled. Overall, the inspector was satisfied that adequate consideration had been made of the MSSS OB leak in the recent reviews of the SAA considered that it would not have a significant effect on the analysis.
    1. review of msss ob leakage INES rating
14. I requested that Sellafield Limited reviewed the INES rating of the ongoing MSSS OB leakage and consider if or when INES three rating would be reached. The UK INES officer assessed [59] Sellafield Limited’s review of the MSSS OB leak INES rating. The officer concluded that the current rating of INES two appears to be valid but observed discrepancies in the licensee’s submissions to ONR that needed to be explained or rectified. The officer made three recommendations:
15. Considering the recently estimated amount of total liquid discharge (≈ 1000 TBq), the licensee should produce, at least once per year, a justified forecast of the leak development and of the time remaining before the INES rating of the incident should be revised.
16. The licensee should use the outcome from (1) above to carry out a thorough analysis of the environmental impact of the leak in terms of risk to the operators, public and environment.
17. ONR should continue the follow-up of the incident development and the relevant actions taken by the licensee, including potential revision of the INES rating.
18. I consider that the officer’s recommendations are covered by the existing ONR engagements on MSSS leakage. The requirements of recommendation one is covered by the monthly leak situation board. Recommendation two is covered by issue 8145 and recommendation three by existing ONR engagements.
    1. Compliance with LC 34, leakage and escape of radioactive material and radioactive waste
19. Regarding MSSS OB leakage, LC 34 (1) requires Sellafield Limited to ensure, SFAIRP, that radioactive waste on MSSS is at all times adequately controlled and contained so that it cannot leak or otherwise escape such control or containment. LC34 (2) requires Sellafield Limited to ensure, SFAIRP, that MSSS OB leakage is detected, notified, recorded, investigated and reported in accordance with LC7 arrangements.
20. Regarding LC 34 (2) requirements for notification, recording, investigating, and reporting in accordance with LC7. I consider that the evidence assessed in this position statement is sufficient to conclude Sellafield Limited has complied with these requirements in respect of MSSS OB leakage to ground.
21. Recognising that MSSS OB continues to leak and could do so for several decades until the source term is removed. ONR’s intervention needed to determine if Sellafield Limited had provided sufficient evidence of compliance with LC34 for the OB leakage.
22. I obtained advice on LC34 (1) and (2) compliance from chemical engineering, chemistry, civil and structural engineering and NLR specialist inspectors.
23. The chemical engineering and chemistry specialist inspectors considered [60] compliance with LC34, taking account of their assessment recommendations presented in section 4.4. The inspectors’ judged that for their specialisms, Sellafield Limited had provided sufficient evidence to support the position that the company has done all that is reasonably practicable to comply with LC34(1) and (2) now. The inspectors consider that the continuing programmes of work, adequately progressed and monitored via new regulatory issues, should support reduction in the associated risks and continued compliance with LC34.
24. The civil and structural engineering specialist inspector, recognising that OB leakage continues, considered [61] whether Sellafield Limited has done all that is reasonably practicable to stop the leakage. In making this judgement, the inspector considered the work delivered by the MSSS OB leakage sub-programme and the planned forward programme of work that is being progressed on in-plant and in-ground mitigation options.
25. With respect to below ground leakage, the inspector was satisfied that Sellafield Limited has identified all reasonably practicable measures to stop or mitigate the leak. The inspector considered that options being progressed to stop the leak may not work, but some measures may mitigate the consequences of the leak. The inspector noted that a further programme of work is in place in relation to in-ground mitigation options.
26. Regarding above ground leakage, the inspector judged there was a compliance gap against LC 34 (1) and that more work, longer-term is needed by Sellafield Limited to demonstrate that it has done all that is reasonably practicable to stop the leak into the south void. This is anticipated to support continued compliance with LC 34.  The inspector’s recommendation 1 covered this shortfall.
27. Regarding LC 34 (2), the inspector noted the recent improvements made to inspect and monitor the above ground void structure for leakage. The inspector judged that there remains a compliance gap with respect to the north and west side outer wall areas masked by the shield walls. The inspector issued regulatory advice that these areas are inspected. The inspector is satisfied that Sellafield Limited has identified a programme of work to inspect behind the walls. It is anticipated that this work will support continued compliance with LC34. The inspector is satisfied that this work can be monitored via routine regulatory engagement and does not require a separate regulatory issue.
28. Subject to recommendation 1 and advice and guidance the inspector is satisfied from a civil and structural engineering perspective that Sellafield Limited has done all that is reasonably practicable to comply with LC 34 (1) and LC 34 (2).
29. The NLR specialist inspector’s assessment [46] focused on the adequacy of Sellafield Limited’s understanding of the leak in the ground and its plans for in-ground mitigation in order to demonstrate that risks to employees and the public associated with the leak are reduced so far as is reasonably practicable both now and in the future. The inspector identified shortfalls included shortfalls associated with continued uncertainty behaviour and location of the contamination in the ground, and identification of potential mitigation measures for two of the leakage pathways. The shortfalls were captured in additional actions to existing issue 8660.
30. ONR’s Technical Inspection Guide[[2]](#footnote-2), LC34: Leakage and escape of radioactive material and radioactive waste recognises the challenges faced with historic facilities and the provisions in place for containment. The actions taken by Sellafield Limited in responding to the leak aligns with the following ONR guidance for inspecting arrangements and implementation captured within Section 6.12:

“*Some historic facilities on nuclear licensed sites are currently being used to store significant quantities of potentially mobile radioactive materials and/or radioactive wastes within a single layer of containment that is of questionable integrity and sometimes located underground. In rare cases, some recognised established leakage and escape cannot be stopped as the required repairs are not technically feasible. In such circumstances the licensee’s demonstration that risks are being managed ALARP should include evidence to demonstrate the reasons why an effective repair to the containment system is not reasonably practicable and the steps that are being carried out in mitigation. The plant should then be managed in a manner that reflects the hazard and risk it presents as a result of the continuing leakage and escape.*

*Inspectors being made aware of this type of situation should raise it to the attention of ONR management and discuss any implications for protection of the environment with the relevant environment agency site inspector. In some cases, the only practicable means of achieving modern standards is removal of the radioactive materials and/or wastes from the facility concerned, to allow a better standard of storage to be secured for the future. In such circumstances, regulatory expectations need to balance the need for waste retrievals to be achieved in a safe and timely manner alongside the need to manage current day risks to levels that are ALARP. It is important that compliance with the requirements of LC34 is given appropriate consideration during the retrieval process itself – this should be addressed in the modification proposals to enable retrievals. Further guidance can be found in ONR’s Technical Assessment Guide on ALARP.”*

1. Noting that this is a challenging and complex problem, based on the evidence sampled, the inspector judged [62] that the work Sellafield Limited has undertaken to date to improve its understanding of the leak and identify potential mitigation measures provided sufficient evidence of compliance with LC34. Notwithstanding current compliance there is work that Sellafield Limited needs to progress that are the basis of issue 8660 additional actions. It is anticipated that the company’s forward plan of work will address these additional actions and support continued compliance with LC34. ONR will monitor Sellafield Limited’s responses to the shortfalls using regulatory issues.
2. Conclusions:
3. In November 2019 Sellafield Limited notified ONR and the Environment Agency that beginning in July 2019, the MSSS original building silo radioactive cover liquor loss rate had increased from 5m3/month to around 1.3 m3/day. The company later confirmed that the increased liquor loss was the result of liquor leaking below ground. In April 2021, the liquor loss rate further increased to around 2.4 m3/day and to date has remained around that rate.
4. Sellafield Limited implemented the MSSS leak management plan that included evaluation of the risks to operators, the public and environment. The company’s initial review concluded that the resultant risks were reduced ALARP. The leakage was rated as an INES two event. The company continues to review the rating because of the continuing leakage of radioactive liquor. It is possible that the OB leakage could continue until the bulk of waste from the OB silos is retrieved, which could take several decades to complete.
5. ONR and the Environment Agency have throughout worked closely on MSSS OB leakage engagements. ONR and the Agency jointly wrote to Sellafield Limited outlining their regulatory expectations for the management of the risks arising from the leakage. Both regulators instigated formal investigations into the leakage. ONR’s investigation concluded with issue of an enforcement letter against a shortfall in compliance with LC34, leakage and escape of radioactive material and radioactive waste. The letter required Sellafield Limited to address level 2 regulatory issue 8145, which was raised shortly after notification of the leakage.
6. Sellafield Limited initiated and delivered an extensive programme of work as part of the company’s leak management plan and provided responses to regulatory concerns. Work outstanding on developing options for leakage characterisation, mitigation, enhanced monitoring and mitigation will be progressed by the MSSS retrievals programme. It is anticipated that the programme of work will support continued reduction of risk arising from MSSS OB leakage SFAIRP.
7. Sellafield Limited judges that the risks arising from MSSS OB leakage remain reduced ALARP. The strategy remains to deliver the earliest start of sustained waste retrieval from MSSS, thereby removing the source of the radioactive leakage.
8. Based upon ONR’s assessment I can conclude that the radiological risks to workers and the public arising from the current and postulated future leakage are low. The integrity of the MSSS OB civil structure is not challenged by the current and postulated significantly higher leakage rates. The leakage chemistry and migration are sufficiently characterised, and supported by suitable monitoring and sampling regimes.
9. ONR specialist inspectors have assessed Sellafield Limited’s responses to regulatory concerns and management of the MSSS OB leakage. The inspectors judged that the company’s responses to ONR’s concerns are sufficient to justify closing issue 8145. The evidence supported either closing the associated actions outright or raising lower-level regulatory issues to manage the shortfalls. The magnitude of the concerns articulated in the lower-level issues are such that they can be addressed by the company after approval of the ONR MSSS OB leakage regulatory position statement.
10. I judge that, in respect of the MSSS OB leakage, Sellafield Limited has provided sufficient evidence to support compliance with LC 34 (1) and (2). My judgement is based on advice provided by ONR specialist inspectors. Notwithstanding this there are some minor shortfalls associated with work included in Sellafield Limited’s MSSS OB leakage forward plan. It is anticipated that this work will support continued compliance with LC34. ONR will monitor Sellafield Limited’s responses to the shortfalls using regulatory issues.
11. Overall, I judge that Sellafield Limited has provided sufficient evidence to support the claim that the risks arising from MSSS OB leakage are reduced ALARP, taking into account delivered and the future planned programme of work. I consider the company has provided evidence that support the claims that the leakage, monitoring, migration and associated risks to workers and the public are adequately characterised and controlled. Also, there is high confidence that MSSS civil structure is robust to very high leakage. The company has identified and are progressing options for mitigating/preventing leakage and further improving leakage characterisation and monitoring.
12. ONR will continue to engage with Sellafield Limited to ensure the company addresses the remaining regulatory concerns.
13. Recommendations

I recommend that:

1. The ONR Sellafield projects sub-division delivery lead accepts ONR’s regulatory position statement on Sellafield Limited’s management of the MSSS OB leakage.
2. The ONR Sellafield projects sub-division management board recommends endorsement for closure of regulatory issue 8145 to the SDFW Divisional Board.

On completion of the transfer of the MSSS OB leak sub-programme to the MSSS retrievals programme, the delivery leads for ONR Sellafield projects and SCIE sub-divisions will make arrangements to transfer regulatory oversight of MSSS OB leakage from projects to SCIE.

1. **REFERENCES**

|  |  |
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| [61] | MSSS OB leakage LC34 compliance civil and structural engineering advice. CM9: 2023/11801. |
| [62] | MSSS OB leakage NLR LC34 compliance statement. |

Appendix 1

Table 1 ONR Regulatory Issue 8145

|  |  |
| --- | --- |
| Action | Action requirement |
| 1 | Sellafield Limited to review and analyse the MSSS environment/safety case for leak to ground to ensure that risks from leakage remain ALARP. |
| 2 | Sellafield Limited to demonstrate that it has adequately characterised the current leak in terms of radiological species, activity and probable source(s) to substantiate the consequence assessment. |
| 3 | Sellafield Limited to demonstrate that it adequately understands the potential migration pathways from leaks at MSSS and identifies outline mitigation response plans for each pathway. The outline mitigation response plans should take account of the realistic timescales to develop and implement detailed solutions verses the credible leak rates such that risk to workers, public and environment is reduced ALARP. |
| 4 | Sellafield Limited to demonstrate that it has adequately assessed the potential effects of the leak on receptors. |
| 5 | Sellafield Limited to demonstrate that it has adequate, substantiated, arrangements for the ongoing monitoring of the OB leak. This should include evaluation of enhanced detection and monitoring systems. |
| 6 | Sellafield Limited to demonstrate that it has evaluated, and where appropriate made arrangements to implement options to prevent, minimise, mitigate or remediate the consequences of leaks from MSSS. SL to implement adequate arrangements for the periodic review of options to prevent, minimise, mitigate or remediate the consequences of leaks from MSSS, and in response to significant changes in the leak characteristics |
| 7 | Sellafield Limited to demonstrate that the retrieval choreography adequately takes account of ensuring that the risks arising from OB liquor leakage remains ALARP and that retrievals remain achievable. |
| 8 | Sellafield Limited to demonstrate that it has adequately assessed the structural integrity of the OB civils structure to high liquor loss rates. |
| 9 | Sellafield Limited to demonstrate that it is adequately managing aging of the MSSS OB reinforced concrete containment. |
| 10 | Sellafield Limited to demonstrate that the company has a resourced programme for undertaking and completing the tasks the company has identified in addressing the above actions |

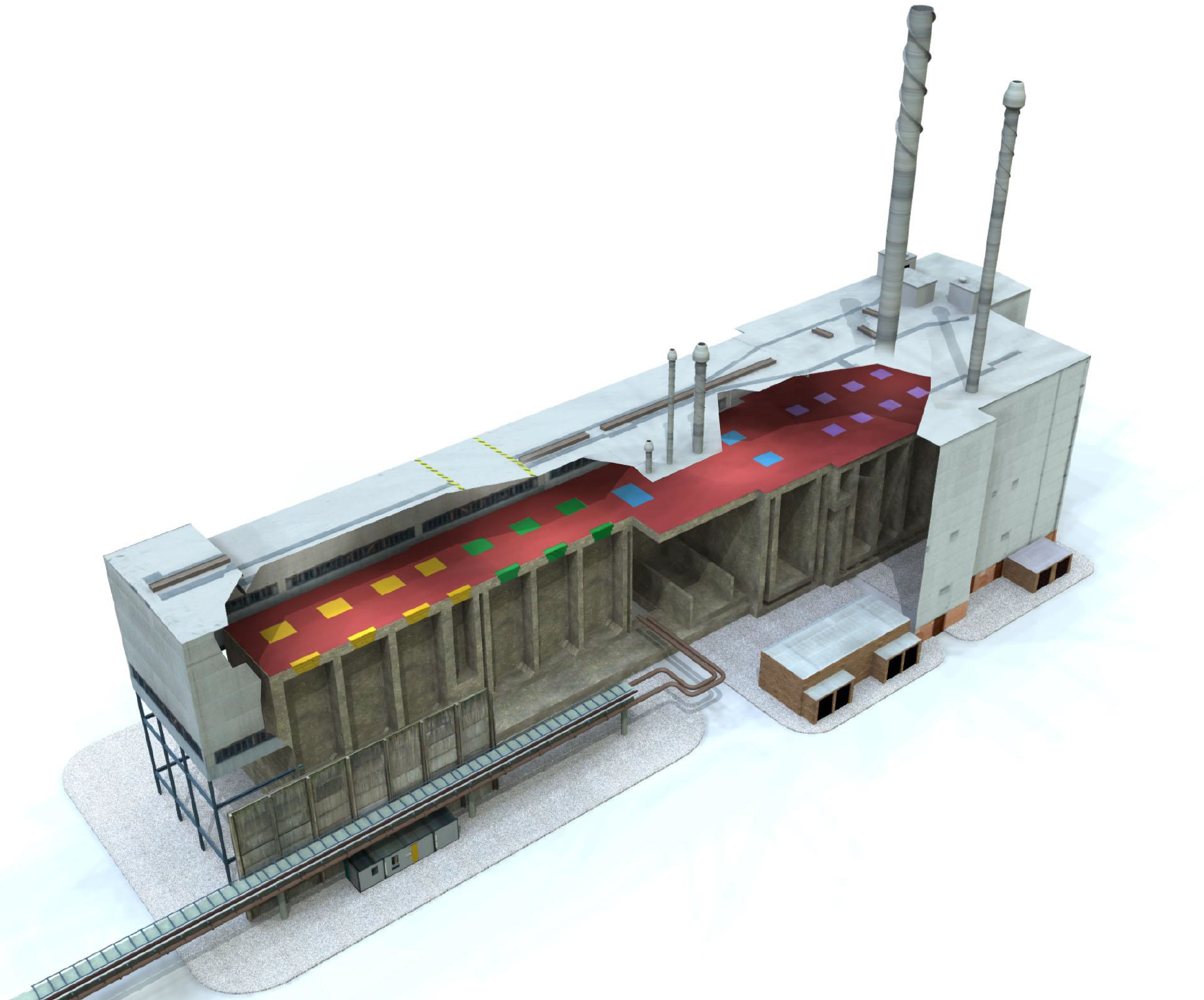


Figure 1: Schematic of MSSS civil structure

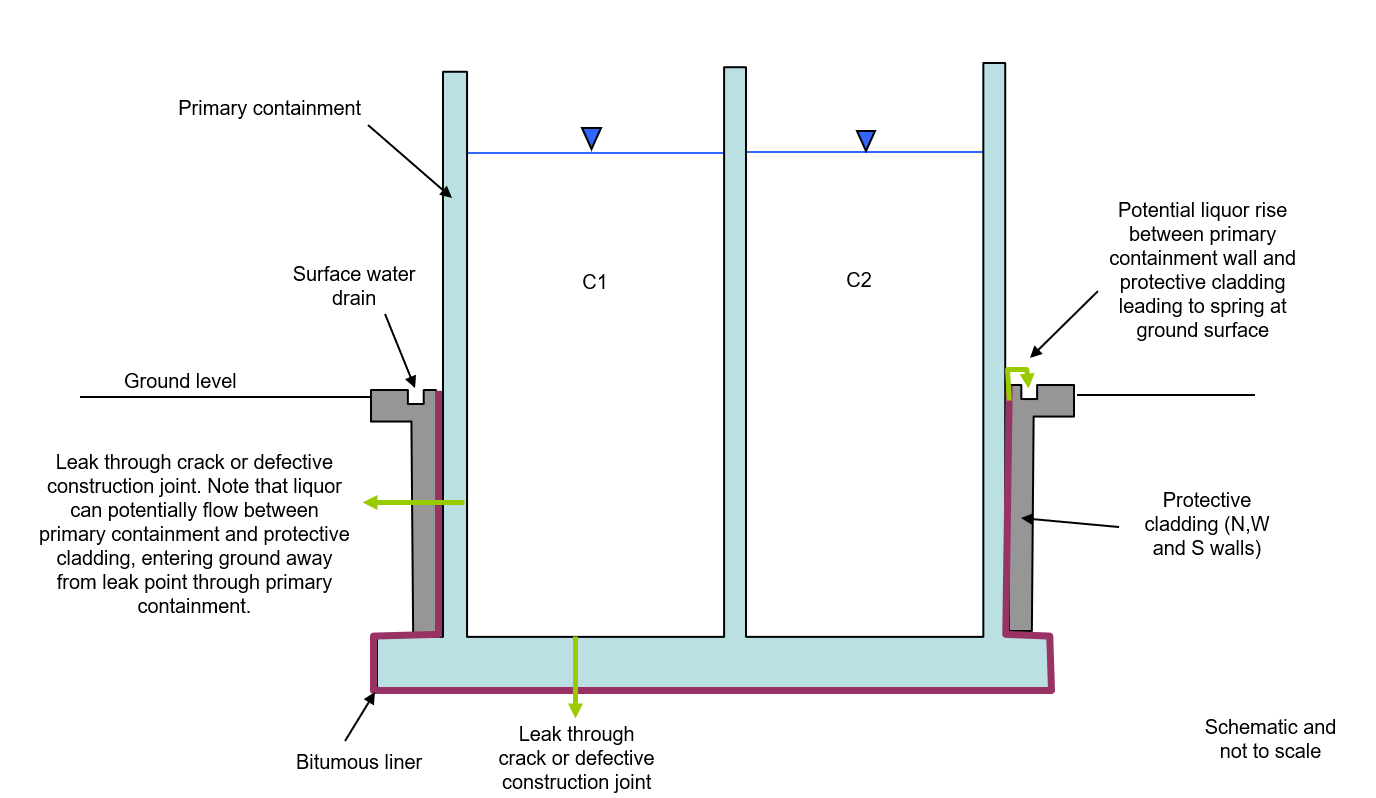


Figure 2: Schematic section of MSSS Original Building with indicative features

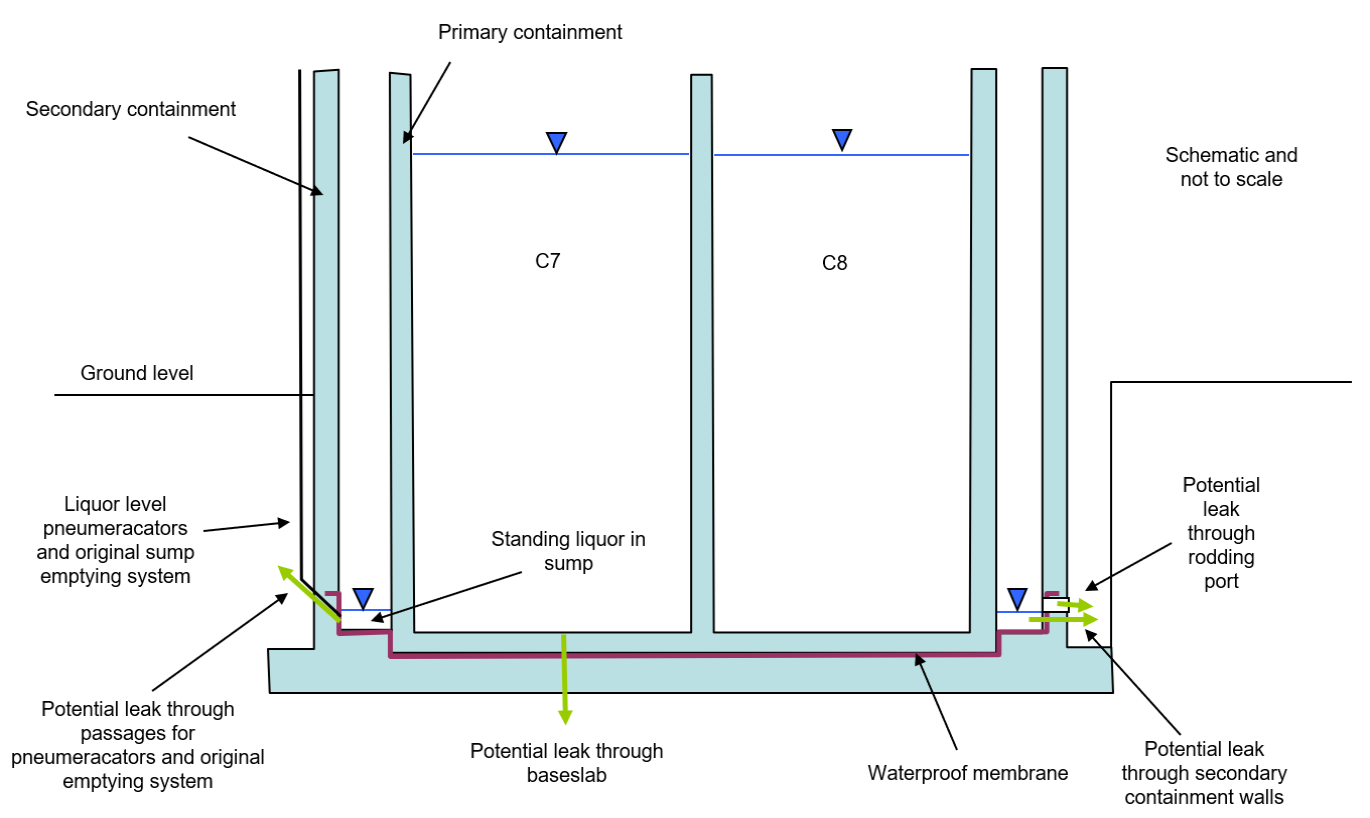


Figure 3: Schematic section of MSSS First Extension

1. [Delivering innovation in the nuclear industry (gamechangers technology)](https://www.gamechangers.technology/) [↑](#footnote-ref-1)
2. [LC34 - Leakage and Escape of Radioactive Material and Radioactive Waste (onr.org.uk)](https://www.onr.org.uk/operational/tech_insp_guides/ns-insp-gd-034.pdf) [↑](#footnote-ref-2)