Regulation of UK Nuclear Legacy Facilities

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Since the inception of the Office for Nuclear Regulation in 2014, the way in which nuclear licenced sites are regulated has continued to evolve in response to the challenges that present themselves. Chief amongst which is the reduction of hazards and risks relating to the facilities from the UK's early nuclear activities. These 'legacy' facilities often fail to meet the standards expected of modern licenced sites and, due to their advancing age, are degrading to the point that the risk of an incident becomes intolerably high. In an attempt to expedite the hazard and risk reduction process, the Office for Nuclear Regulation has adopted an approach which aims to work with licensees and stakeholders to enable fit for purpose solutions that must balance the increase in short term risk in order to effectively achieve reductions in the long term. The purpose of this paper is to provide an insight into how the Office for Nuclear Regulation makes regulatory judgements regarding these problematic facilities. An example will provide context for the complex challenges presented by legacy facilities and shed light on the risk-based decision making process that enables a balance to be found between ensuring timely reduction of long term hazards while ensuring that the precursory short term risks are reduced so far as is reasonably practicable.

Keywords: Nuclear, ONR, Enabling Regulation, Legacy Facilities, Risk, Hazard, ALARP

Introduction

The terms 'hazard' and 'risk' have become almost interchangeable in the English lexicon. However these terms are in fact distinct from one another. Hazard can be used to describe anything which can cause harm. Risk, on the other hand, is the probability of harm occurring in a given situation (Office for Nuclear Regulation, 2017). Within the nuclear industry the hazards are many therefore the risks must be reduced so far as is reasonably practicable. The nuclear industry in the UK dates back to the end of the Second World War. Following the Windscale Piles Fire of 1957 the requirement for regulation of nuclear activities was realised. This led to Nuclear Installations Act 1959 which paved the way for the formation of the Nuclear Installations Inspectorate (NII). In the intervening years the regulatory framework that supports the industry has evolved alongside it. Since 2014, regulation of nuclear activities within Great Britain has been carried out by the Office for Nuclear Regulation (ONR), an independent body. Amongst the numerous areas in which ONR are involved, one of the organisation's most pressing challenges is that of the early nuclear facilities that are at, or nearing the end of, their working lives. Retrieving the radioactive inventories from these older facilities is paramount to long term hazard and risk reduction however efforts have historically been hampered due to the condition of the structures. These unique challenges have prompted ONR to adopt an enabling approach to the way in which these facilities are regulated.

Overview of UK nuclear industry

The UK nuclear industry traces its roots back to the 1940s when the Windscale reactor was built on the Sellafield site in Cumbria, diverting priorities from conventional munitions to the development of nuclear weapons. This sparked a rapid growth in nuclear activities in the UK, including the world's first commercial nuclear power plant at Calder Hall. In the 21st century, the nuclear industry consists of a variety of activities spanning power generation, fuel production, reprocessing, research, the building of new facilities and the decommissioning of older plants.

A considerable portion, roughly a fifth, of the UK's electricity supply is produced by nuclear power plants. Providing this power are the 15 operational reactors in service across 8 sites (Office for Nuclear Regulation, 2016). While Pressurised Water Reactor (PWR) designs are the most common design worldwide, all of the UK's power-producing plants – with the exception of Sizewell B – employ Advanced Gas Cooled Reactors (AGR) (Office for Nuclear Regulation, 2016). A map of the various UK nuclear sites can be found in Figure 1.

The AGR reactors that are still in operation are known as the second generation of nuclear power plants. Their predecessors make up the first generation, consisting of ten Magnox (named as such due to the magnesium alloy cladding) reactors that were built between 1956 and 1971. These plants are now owned by the Nuclear Decommissioning Authority (NDA) and are all in varying stages of decommissioning, the last of which to be operational, Wylfa, ceased production in 2015.

As well as power plants, there is a variety of non-power producing activities taking place within the industry. These include but are not limited to; research activities, waste disposal, fuel manufacture, reprocessing, medical products manufacture and waste storage. As with the first generation power plants, many of the older facilities have reached the end of their operational lives and are in, or preparing for, decommissioning. The majority of these older sites are now under the ownership of the NDA (Office for Nuclear Regulation, 2016).

Looking to the future, decommissioning projects will continue with the current fleet of AGRs set to cease production in the near future, beginning in 2023 (BEIS & NDA, 2019). Until recently there were several proposed new build reactors planned, however due to a number of factors many have been cancelled or put on hold. Only one proposed new build has commenced construction at Hinkley Point C, with plans for another proposed site at Sizewell (EDF Energy). At Hinkley Point C, EDF Energy's pair of European Pressurised Water Reactors (EPRs) will be the first new plants built in the UK for over 25 years and will join Sizewell B as the third generation of reactors.

Sellafield, the UK's largest and most complex nuclear site, has been home to a variety of activities spanning the nuclear fuel cycle, from research reactors to power production and later spent fuel reprocessing from reactors around the world. The last reprocessing operations are set to be completed in 2020, after which efforts at the site will be focussed on decommissioning and other aspects of hazard and risk reduction (NDA and Sellafield Ltd, 2018). The facilities at Sellafield contain inventories of varying categories of nuclear waste, making Sellafield one of Europe's most unique and complex nuclear sites.

Globally there is a push to develop long term disposal solutions for nuclear waste. In Finland, work has begun on construction of the world's first geological disposal facility (GDF). It is the view of the UK Government that a GDF similar to Finland's is the optimal solution, whereas the Scottish Government prefers a different approach in the form of a 'near surface, near site' solution (Lochhead, 2007).

As the AGR fleet begin to be taken offline, an energy deficit is likely to arise. Research is underway into small modular reactors (SMR) and advanced modular reactors (AMR) which offer advancements in safety, efficiency, reliability and proliferation resistance. This new generation of reactors may have a role to play in the future energy mix.

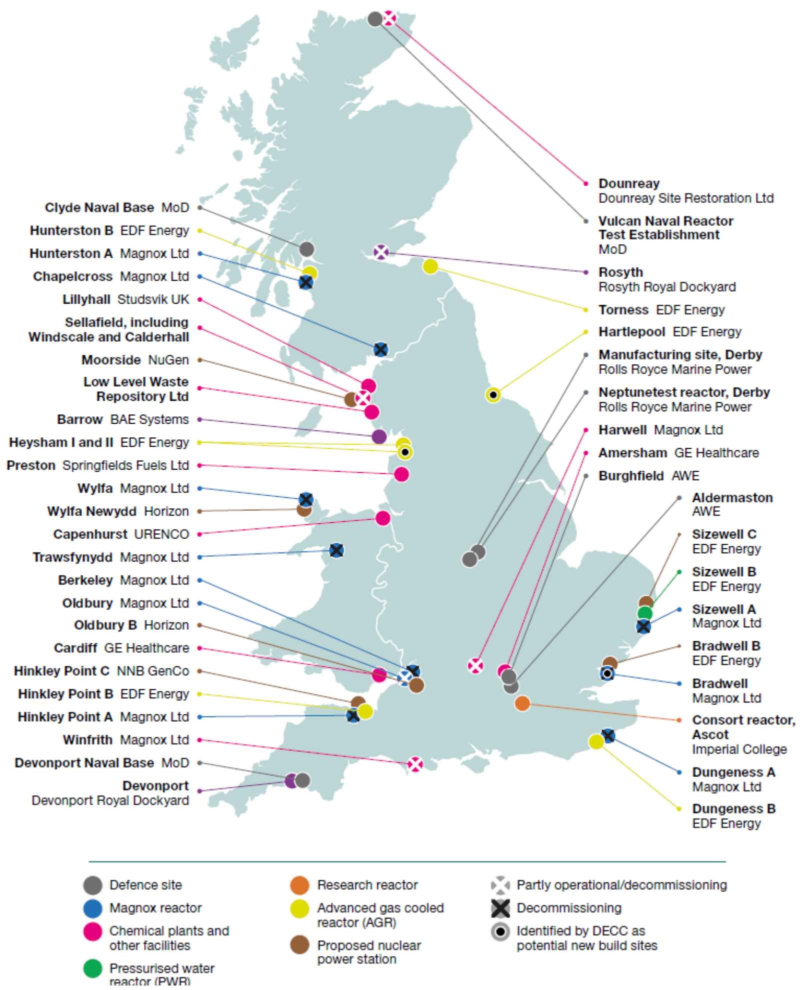

Figure 1: Map of UK Nuclear sites (N.B the GE Healthcare facility in Cardiff has recently been de-licensed following a period of decommissioning)

Regulation of the Nuclear Industry

Early in the development of the UK nuclear industry, it became apparent that due to the hazards associated with the various activities, a regulatory framework would be needed. The Nuclear Installations Act 1965 enabled the NII - the predecessor to ONR - to attach conditions to a nuclear site licences. In order to receive a licence, any corporate entity engaging in nuclear activity must demonstrate that they will adhere to these licence conditions. Failure to do so is a criminal offence (Nuclear Installations Inspectorate, 2006).

The Energy Act 2013 created ONR, moving regulation of the nuclear industry out of the Health and Safety Executive to the new statutory public corporation. ONR was established with the mission to provide "efficient and effective regulation of the nuclear industry, holding it to account on behalf of the public" (Office for Nuclear Regulation, 2016). This afforded ONR greater independence to administer regulation of the nuclear industry, free from industrial and governmental influence. As set out in The Energy Act 2013, the ONR's purposes can be broken down into five areas;

- Nuclear safety: protecting the public from the potential risks that are associated with nuclear activity
- Nuclear site health and safety: Protecting workers on nuclear sites
- Nuclear security: maintaining the security of nuclear facilities and inventories
- Nuclear safeguards: Ensuring that the UK complies with the various safeguard agreements which it has entered
- Transport of radioactive material: Extending the protection of the public, workers and environment to the transport of radioactive material as it is moved around the country

(Office for Nuclear Regulation, 2017).

ONR regulates the 36 licenced nuclear sites across the UK covering a variety of activities from operational reactors to decommissioning of older facilities. To cover all of its purposes the organisation is divided into five regulatory divisions: New Reactors, Operating Facilities, Civil Nuclear Security and Safeguards, Technical Division and Sellafield, Decommissioning, Fuel and Waste (SDFW); the last of which is the division of interest in this paper.

The Energy Act 2013 – along with the Health and Safety at Work Act 1974 (HSWA) and the Nuclear Installations Act 1965 – underpins the regulation of the nuclear industry in the UK (Office for Nuclear Regulation, 2016). In order to build or operate a civil nuclear facility, the organisation must receive a site licence. Attached to this is a set of 36 standard licence conditions that set out the requirements to which the duty holder must adhere. On the whole, the licence conditions are not intended to be prescriptive i.e. it is not the role of the regulator to instruct the licensee on how to carry out their specific activities safely, instead the duty holder must "make and implement adequate arrangements to cover a particular aspect important to safety" (Nuclear Installations Inspectorate, 2006). This 'goal-setting' approach provides flexibility for the duty holder to apply their own expertise to address each particular challenge. The duty holder must then provide evidence to demonstrate that they have complied with the requirements of the licence conditions.

To enforce the relevant legislation, ONR appoints inspectors through a warranting process. The warrant gives an inspector a range of powers which they apply in line with the enforcement policy statement and principles. This can range from offering advice to holding the duty holder to account if they are failing to comply with one or more legal provisions. As the nature and severity of the situation increases the inspector can take a number of actions depending on the context, including issuing improvement notices, prohibition notices or bringing the breaches of the law before the courts through prosecution.

While ONR are responsible for regulating the industry, the responsibility for safety on the licenced site falls upon the duty holder. If an activity may have an adverse effect on any aspect of nuclear safety then a safety case must be provided, to demonstrate that risks have been reduced to as low as is reasonably practicable (ALARP) and the procedure is being carried out in a safety conscious manner (Office for Nuclear Regulation, 2016). ONR inspectors then use their own judgement to assess whether or not the legal requirements are being met and if not; action will be taken that is deemed proportional to the situation. To ensure consistency in the way in which the law is applied, the inspectors assess against a set of Safety Assessment Principles (SAPs). These, in turn, are supported by Technical Assessment Guides (TAGs) and Technical Inspection Guides (TIGs) that provide additional detail to the SAPs. For the sake of transparency and in effort to assist duty holders to understand the judgement process, these documents are freely accessible. (Office for Nuclear Regulation, 2019)

In assessing whether a risk is unacceptable, the ONR employ the 'tolerability of risk' concept which is illustrated using the 'inverted triangle' diagram shown in Figure 2. This allows risks to be categorised into three levels, or zones.

- At the top is the unacceptable zone. Risks in this area are deemed to be so severe that they cannot be justified unless under exceptional circumstances.
- The middle region is the tolerable zone where the focus of the ONR is on assessing whether the duty holder has complied with the law and reduced the risk to ALARP.
- Finally at the base is the broadly acceptable zone for a level of risk which is sufficiently low that it is not worth the required resources to reduce it further.

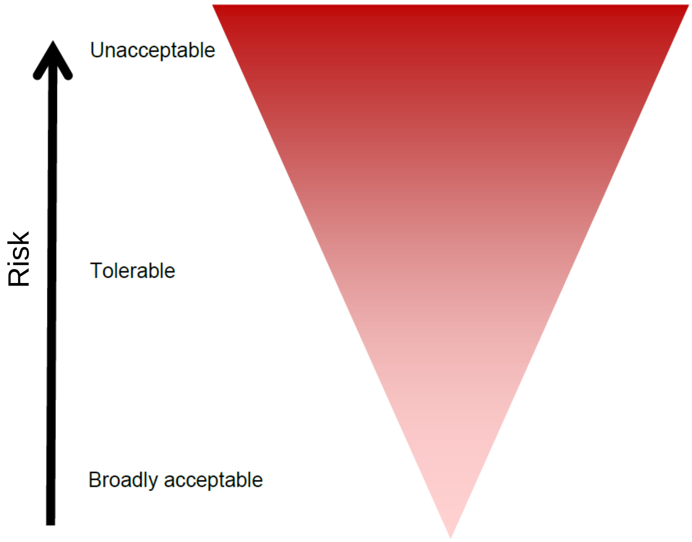

Figure 2: Tolerability of Risk, 'Inverted Triangle' Diagram

In order to judge what constitutes ALARP, the level of risk and by how much it can be reduced is balanced against the financial cost, time and effort, required to achieve the risk reduction (Office for Nuclear Regulation, 2017).

The Regulation of Legacy Facilities

In the rush to develop nuclear capability, many of the UK's early nuclear facilities were constructed with little regard for how they would be decommissioned or how their inventories would be retrieved in the future. These facilities, some of which are now over 60 years old, are known as 'legacy facilities' and are home to a variety of complex inventories of radioactive fuel and waste which must be removed to enable decommissioning.

The condition of many of these buildings is well below that expected of modern facilities, this has added to the complexity of the task and has hampered attempts to remove the inventory safely. Their condition is such that the ONR deem them as currently unacceptable or likely to become unacceptable in the future. Due to poor record keeping, the exact details of much of the legacy facility inventories are unknown, further adding to the challenge as characterisation of the inventories is essential so that the waste can be transferred to long term storage when a geological disposal facility is available.

What is known however, is that these facilities contain material that has a level of activity that is hazardous at present and will remain so beyond the lifespan of the buildings in which it is contained. As the surrounding infrastructure ages, the complexity of the challenge of removing the legacy materials increases. If the material is left in place then it becomes increasingly likely that the related infrastructure will degrade to the point of a radiological incident occurring. On the other hand, taking intrusive action to remove the inventory from the aging facilities that are now in varying stages of degradation brings with it an immediate level of risk to the operators, public and environment. Therefore, a balance must be struck between the short term risk associated with taking action and the long term hazard which would result from choosing to do nothing.

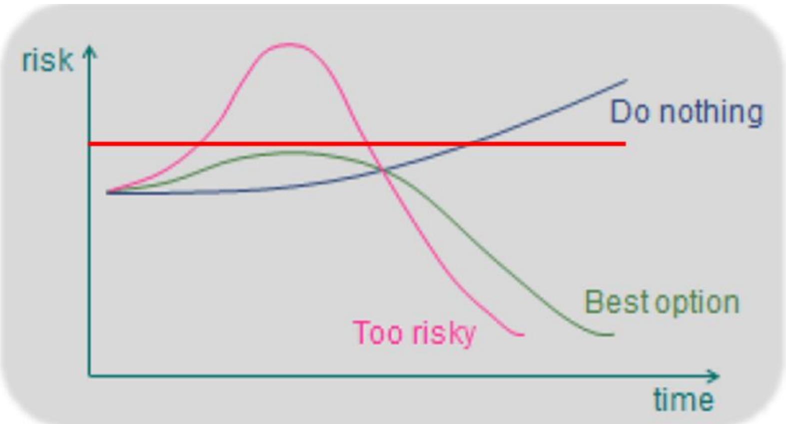

Figure 3: Risk profile of potential courses of action

Figure 3 depicts the different risk profiles of the various courses of action that can be taken on legacy facilities. Following the blue 'do nothing' line, it is clear that as time progresses the risk of a radiological event increases due to the deteriorating condition of the facilities. At a certain point the risk reaches the point at which it crosses the red line signifying that it has become intolerably high. Many of the legacy facilities are closing in on the red line or have already crossed over into the intolerable region. Therefore choosing to take no action serves only to push the issue further down the line while the likelihood of a serious incident increases. It should be noted however; in reality the boundary between tolerable and intolerable is not so clear. Instead, there is a degree of judgement involved.

It is therefore advantageous to take a more proactive approach to addressing these challenges. The pink and green lines show the risk profiles of two forms of intrusive action. While the pink route achieves overall reduction earliest, the accompanying short term risk is such that it is likely to be intolerably high. Thus, the green line shows the optimal solution. As before, although making intrusive action may increase the risk in the short term, it allows the goal of accelerated hazard and risk reduction to be realised. When compared to the latter option, it can be seen that the pink route has failed to reduce the short term risk to ALARP. The green route, on the other hand, achieves the overarching goal of hazard and risk reduction while ensuring legal compliance.

These legacy facilities can be found across Britain, from former research sites such as Dounreay on the North coast of Scotland to first generation Magnox reactors at locations like Dungeness A. Many of the most challenging legacy facilities are located at Sellafield, a two square mile site in the North West of England which was central to the UK's reprocessing programme. Sellafield is now considered one of Europe's most complex and hazardous nuclear sites and as a result, ONR has made the accelerated reduction of hazards at these legacy facilities the organisation's top priority.

Taking into account the scope of this challenge and learning from past experience, ONR launched a new approach in 2014 which focussed on "stimulating, facilitating and expediting Hazard and Risk Reduction" (Winspear Roberts, 2016). This new strategy has been implemented in order to achieve three primary objectives:

1. Accelerated hazard and risk reduction
2. Evidence based confidence that the licensee is complying with its statutory obligations and that workers and the public are protected from the hazards of the site
3. Stakeholder confidence that ONR's regulatory approach is appropriately targeted, risk based, proportionate and effective

ONR recognise that many of the facilities lie within the intolerable region and that delaying the removal of the inventories will only exacerbate the problem further, hence the change in approach. To aid in putting the new strategy into practice, a number of key themes were identified:

Common priorities

The G6, a stakeholder group was established consisting of NDA who control Sellafield and other civil legacy sites, Sellafield Ltd who operate the site, regulators in the form of ONR and the Environment Agency as well as governmental representation from UK Government Investments and the Department for Business, Energy and Industrial Strategy. This group facilitates cooperation so that all stakeholders can acknowledge that efforts must be made to align priorities so that focus can be given to those projects which can lead to long term reductions in hazards.

Effective use of resources

An understanding of how best to implement the resources available should be developed to ensure that the objectives can be met. Central to this theme is ONR working with licensees to empower their own internal regulation which will allow for more efficient regulation of lower priority projects.

Removal of blockers and bureaucracy

ONR has identified that their previous approach to regulating legacy facilities had become overly reliant on procedure and was hindering innovation and ultimately prevented progress towards long term hazard reduction. ONR, along with licensees, must strive to streamline the regulatory process while maintaining legal compliance.

Removal of distraction and diversions

With reference to Sellafield, ONR had previously treated each facility in isolation. This led to a lack of overall direction and as additional issues were raised, these diverted attention and resources from the reduction of the highest hazards and risks which should have been the priority.

Incentives and Disincentives

Incentives should be put in place to ensure that the priorities of those contributing to the project align with the overall strategic aims of expedited hazard and risk reduction. Where possible, incentives which serve to distract from the overarching objectives should be removed.

"Fit for purpose" solutions

It was identified that work being done on legacy facilities was overly complex and the standards set were unrealistic given the condition of the facilities. This approach lengthened the time taken to deliver projects and led to complications which ultimately prevented hazard reduction. By adopting a more pragmatic approach, ONR enabled the licensees to develop 'fit for purpose' solutions that are specific to the individual facility and its particular characteristics, ultimately leading to accelerated hazard reduction.

Balance of risk

Due to the degraded condition of many legacy facilities, it can be anticipated that in order to achieve long term solutions some increase in short term risk must be tolerated. In the past, failure to acknowledge that this increase is necessary has resulted in inaction, allowing the infrastructure to degrade further and making the task more difficult. It is pertinent to note however, that this does not mean that the standards expected by ONR are reduced. A balance must be struck to ensure that the short term rise in risk is controlled in order to allow for the long term hazard to be addressed.

Communications

This novel approach to regulation is likely to spark interest with the many stakeholders. It is imperative then that there is a culture of open communication between stakeholders, licensees and regulators. This will ensure that nobody is caught off guard by the accelerated pace of activities and all involved understand the reasoning behind the decisions being made.

While these themes have been developed specifically to ONR's approach to Sellafield, the learning can be applied across the wider legacy area. There is an element of interdependency within the key themes. For example, with regards to making intrusive modifications to legacy facilities, once priorities have been agreed between the licensee, regulators and other stakeholders, ONR can be confident that all involved are working towards a shared goal. It is therefore in ONR's interests to adopt a model which enables action to be taken so that meaningful progress can be made towards hazard and risk reduction. Striking a balance between the desire to reduce the long-term hazard with the associated increase in short term risk requires fit for purpose solutions. Fit for purpose has been defined as; "legally compliant but appropriate to the particular risks which have to be controlled" (Office for Nuclear Regulation, 2018). This allows for inspectors to use their judgement on a case by case basis in recognition of the aging infrastructure and determine if the risks have been reduced to ALARP, given their particular context.

To achieve a substantial reduction in the risks posed by legacy facilities, activities which require regulatory permission must be carried out. As with other licensed sites, a safety case must adequately demonstrate that the work can be done in a legally compliant manner. Taking into account the challenging nature of the legacy facilities, ONR's approach is one of 'enabling regulation' which seeks to work constructively with the duty holder to achieve effective delivery of objectives safely and securely (Office for Nuclear Regulation, 2018). This enabling approach does not mean however, that the ONR mission to hold industry accountable is undermined. The regulator will still use its powers of enforcement to ensure that the law is being adhered to; however these will be applied proportionately to the particular issue.

Where increases in the near term risk cannot be reasonably avoided, each modification will be treated in a case by case fashion. In doing so, ONR will consider a number of factors when formulating a balanced regulatory decision. These include:

- The residual level of risk following the modification
- The short term risk to operators and the public which is likely to arise as a result of the modification
- The level of risk to society from the hazard in its current, unmitigated form

- The nature of the proposed engineering solution and the extent to which they fall below relevant good practice
- Degree of uncertainty of the risks posed by the legacy facility
- Extent to which time at risk arguments contribute to the overall defence in depth
- Balance of emphasis duty holders place across the various engineering and administrative facets of a multifaceted defence in depth hierarchy
- Overall justification presented by the duty holders which demonstrates that the short term increase in risk is balanced by long term risk reduction.

Enabling Regulation in Practice

An example of a facility which has undergone intrusive modifications in an effort to achieve accelerated reduction in hazards and risks is Sellafield's Legacy Silos. Examination of the progress made towards this overarching objective provides a helpful insight into how the philosophy of enabling regulation is applied in reality as well as the many, sometimes competing, factors which are taken into account when making regulatory judgements.

In the early 1950s, the Legacy Silos facility was constructed on the Sellafield site to store miscellaneous intermediate level waste (ILW) from the Windscale Piles. Later, in the 1960s waste was added from the Calder Hall reactors. The facility consists of several compartments which house an inventory known to comprise an assortment of high hazard materials. Based on a 1940s design, the building, like many legacy facilities, has degraded over time and the risk of a radiological incident with far reaching consequences has become intolerably high. It was therefore deemed a priority to retrieve the waste from the aging silos and house it in a modern facility where it will be stored safely until it is ready to be relocated to a long term storage solution. At present the UK government policy is to construct a GDF, the location of which has yet to be decided (Department of Business, Energy and Industrial Strategy, 2018). Thus, it is likely that the interim storage facility will have to operate for some considerable time before treatment and disposal can be carried out.

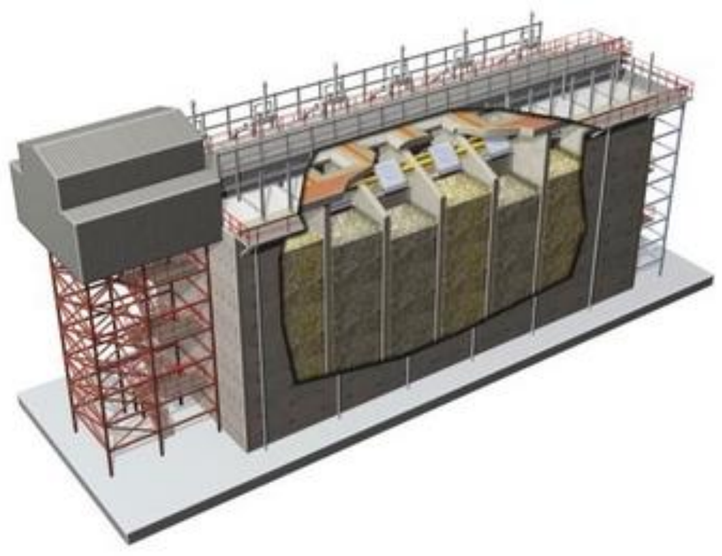

Figure 4: Legacy silos before retrievals modifications

The Legacy Silos facility has a number of hazards and the safe continued storage of waste relies on the continued injection of argon gas to exclude oxygen and minimise the risk of fire. Failure of these safety measures could result in a significant release of radioactive material as well as a potential knock-on effect for nearby facilities. It is accepted that in order to bring the risk down into the broadly acceptable region, the waste from each compartment must be removed and relocated for storage in a modern facility which would allow for passively safe storage (Gildart-Butler & Higham, 2015).

In 2013, retrieval of waste was paused due to spiralling costs and uncertainty concerning the deliverability of the retrievals process. The cause of this was attributed to an excessively restrictive safety culture, reliance on complex engineered solutions and the deterioration of relationships between stakeholders (Sellafield Ltd, 2013). A strategic review brought about the recognition that there is no zero risk method for retrieving the inventory. Doing nothing will only allow the facility to degrade further and increase the likelihood of a serious event occurring. It is therefore accepted that in order to make meaningful progress towards retrievals an increase in short term risk must be anticipated. The 'goal post' diagram (Figure 5) shows that while the facility is not yet at the emergency response point, the conditions are far from what would be considered normal operation. It is important to note however, that while ONR's strategy of enabling regulation focuses on supporting Sellafield Ltd in achieving the shared goal of expedited waste retrieval, legal compliance is still paramount, i.e. any short term increase in risk must be reduced to ALARP.

Figure 5: Goal Post Diagram for the Condition of Legacy Silos

The traditional view taken by ONR to relevant good practice with regards to retrieval operations is to first retrieve the waste, passivate it using a suitable process and then store the waste to wait for long term storage.

However, due to ambiguity surrounding the composition of the silo inventory, the time required to design an adequate passivation facility is such that it would significantly hamper the ability to remove the waste in a timely manner, allowing the silo to degrade further and moving the facility further into the intolerable region. Therefore, the licensee adapted their approach to prioritise retrieval so that the waste could be removed as soon as reasonably practicable. The solution was to proceed with retrievals and store the unpassivated waste in $3m^3$ stainless steel boxes which would then be transferred to a facility of modern standard for interim storage, alleviating the time pressure for a suitable passivation process to be developed. Despite being a deviation from relevant good practice, this change in approach enables progress to be made in reducing the overall risk. Moreover, while retrievals are being carried out, the inventory's composition can be assessed. This, in turn, enables viable passivation options to be explored that can be aligned with the specification required for storage in the GDF. ONR judged that the overall ALARP position adopted by Sellafield Ltd was adequate as it contributed to the common goal of accelerated hazard and risk reduction.

Due to the degradation of the silo, the risk associated with mounting the retrieval equipment on top was deemed too high and as a result, progress was impeded. It was therefore decided to explore different points of entry. The fit for purpose solution chosen by the licensee was to build an external retrievals superstructure adjacent to the silo. Doors would then be cut into the side of each compartment through which the waste can be removed. The material can then be transferred to the $3m^3$ boxes before being transferred to the interim storage facility. Some of these early decisions were made by Sellafield Ltd some time before the change in regulatory approach, paving the way for the introduction of enabling regulation.

Much of the silo content is flammable. As of the late 1990s, the building has been continually inerted using argon gas to minimise the risk of fire. The reliance on continuous inerting, a preventative measure, was identified as a weakness in defence in depth. In order to address this, additional mitigation was required. The fit for purpose solution chosen came in the form of an off-the-shelf fire detection technology, supplemented by a powder fire fighting system (Office for Nuclear Regulation, 2016).

Whilst the silo has received significant structural strengthening, it still falls short of the standards expected of a modern facility. The safest option to remove the waste from the compartments is to use a conventional crane with a grab which is used to reach in and retrieve the material. In order to gain unrestricted access to the compartments, deflector plates, large steel plates which directed the waste into the compartments while the silo was being filled, must be removed (Office for Nuclear Regulation, 2016). Work began on removing the first plate in 2015. The challenge of choosing a cutting process was to select a technology that would be effective in removing the plate while balancing the increase in short term risk. Once again, it was acknowledged by Sellafield Ltd that there was no perfect solution available and thus came to the decision that the most appropriate course of action would be to use water jet cutting technology. At the time, this was a relatively novel application of the technology and, considering the nature of the inventory, the introduction of water was likely to bring about a risk of increased hydrogen production due to the reaction with water. Conversely, waiting until other solutions became available would result in lengthy delays to the removal process. In order to ensure that risks were reduced to ALARP, an enhanced level of engagement was employed between Sellafield Ltd, ONR and other stakeholders. This included a stakeholder communication plan to facilitate easier communication as well as fit for purpose hydrogen sampling techniques. The water quantity was also closely monitored to ensure that hydrogen level did not rise above the lower flammability limit (Office for Nuclear Regulation, 2016).

Originally the use of cranes for external lifting was to be minimised due to the increased risk associated with working in such a congested area. However, the alternative would bring about a significant increase in dose received by the workforce. Thus, a balance between conventional and radiological risk was sought and, in the end, controlled crane lifts took place. Containment doors were then cut into the side of each compartment. Aside from making considerable changes to the building, the cutting of the doors was, by definition, a breach of containment. Once again, to make progress towards retrievals it was necessary to accept an increase in short term risk profile. In order to control the risk, there was a shift in focus from preventative measures to mitigation. As well as engineered solutions, increased focus was given to the effectiveness of emergency arrangements (Office for Nuclear Regulation, 2016).

In the last year, progress has been made towards retrieving the waste with the installation of the retrievals facility. This progress has been aided by the application of proportionate but efficient regulation from ONR. During the installation phase, formal permissioning was required to ensure safe design of the facility. However, in the following inactive commissioning phase, permission from the regulator was not required (Office for Nuclear Regulation, 2018). Hence, unnecessary bureaucracy can be removed by adopting a streamlined regulatory approach. The next stage of active commissioning brings with it an increase in risk, therefore, will require formal permissioning.

The ambiguity surrounding the composition of the inventory of each compartment presents another stumbling block. To reduce, not only the increase in risk, but the time spent at risk, an approach of ‘lead and learn’ has been adopted. First, early retrievals will be carried out from one compartment. This will allow for a start to be made in removing the waste while allowing for the composition to be assessed during the retrievals process, thus taking steps towards addressing the uncertainty. This will enable continuous refinement of the waste retrieval process by collaboration with stakeholders and the supply chain allowing for flexible solutions which will make future retrievals quicker and safer.

Discussion

Recent progress on the waste retrieval project from the Legacy Silos facility is testament to the tangible impact this change in regulatory approach can have. While the wider, proportionate regulatory approach from ONR is to reduce the risk posed by legacy facilities to ALARP, there are numerous modifications which must be made to enable the inventories to be retrieved. Each modification - and all associated activities - must also be carried out in a legally compliant manner with risks reduced to ALARP. In making regulatory judgements, a balance must be struck between ensuring that each activity is carried out safely while not losing sight of the overarching objective. Thus, ONR will treat each activity on a case by case basis that will allow for proportionate regulation to be exercised so that progress can be made to the larger scale ‘programme ALARP’. The following are some of the aspects which will be considered when forming a regulatory judgement:

- **The residual level of risk following the modification**
  The waste will be stored on site until a permanent storage solution is ready. Permanent storage is unlikely to be available at any point in the near future therefore the intermediate storage facility will be operational for a considerable time. However, being a newly built facility, this will be constructed to modern standards and regulated accordingly. By storing the waste in $3m^3$ boxes, even in the event of a fire in a single box, the risk of it spreading to the rest of the waste is reduced. Therefore the long term risk of will be will be reduced to ALARP.
- **The short term risk to operators and the public which is likely to arise as a result of the modification**
  In order to achieve accelerated hazard and risk reduction, waste that has been quiescently stored for decades will have to be disturbed. This will, by its nature, introduce an increase in short term risk that is further compounded by the lack of understanding of the condition and composition of the inventory. Each modification contributing to the overall programme ALARP will bring with it some degree of risk that must be controlled. As discussed, the silo has exceeded its design life which compounds the risk associated with the additional stress that accompanies the necessary modifications.
  These works are likely to add to an already congested area of the site. The use of lifting equipment poses a risk to ground level operators. The risk due to the breaking of containment must be carefully managed so as to limit the dose which operators are exposed to, as well as limiting the oxygen ingress to the previously inerted inventory. Given the increased reliance on operator interaction, the risk of argon asphyxiation must also be considered.

- **The level of risk to society from the hazard in its current, unmitigated form**
  The facility has degraded over time to the point that failure to retrieve the waste increases the likelihood of a serious incident to an unacceptable level. Waste fires, in particular, could cause damage to the structure meaning that containment could be compromised. It is accepted that, left in its unmitigated form, eventually the condition will be such that safe retrievals will become impossible. The facility is located in close proximity to other high hazard legacy facilities and there is a risk that an incident in this facility could have a serious knock on effect on the others, with potentially significant societal consequences.
- **The nature of the proposed engineering solution and the extent to which they fall below relevant good practice**
  In order to allow for removal of the waste, a retrieval facility has been built adjacent to the silo. Holes have been cut in the walls of each compartment through which the waste will be transferred to the new building. It is understood that in order to gain access to the waste, air ingress is possible, raising the risk profile. The current safety case conservatively ensures very low levels of oxygen within the silo. However, it has been recognised that such low levels may not been achievable at all times during waste retrieval. Additional scientific analysis - in conjunction with silo enhanced monitoring and the aforementioned fire protection improvements - may enable some relaxation in the current limits in order to support safe and sustained retrieval operations in the future. This case is currently being considered by ONR.
  Another issue which prevented access to the waste was the large metal deflector plates that needed to be cut into smaller pieces so that they can be removed. The method chosen by Sellafield Ltd was to use a water jet to break apart the waste items. This introduced water to the silos, increasing the risk of waste fires and hydrogen excursions. While the normal good practice would be to avoid the introduction of water, it was accepted that there was no risk-free method available. Further refinement of options would significantly hinder progress towards the programme ALARP.
- **Degree of uncertainty of the risks posed by the legacy facility**
  There is a lack of clarity regarding the composition of the waste inventory particularly as it comprises a variety of miscellaneous ILW. The lead and learn approach to retrievals will provide an opportunity for the licensee to view the inventory, clearing up the ambiguity and allowing for changes to be made to future retrieval plans based on the improved understanding. There is uncertainty over the structural integrity of the building and the potential loss of containment. While it is recognised that the facility was beyond its design life, it is difficult to accurately quantify the level of structural degradation and how long safe operation is likely to last.
- **Extent to which time at risk arguments contribute to the overall defence in depth**
  Reflecting on Figure 3 - While it is imperative to limit the magnitude of the short term risk increase, it is equally important to ensure that the time spent at this elevated level of risk is reduced so far as is reasonably practicable. For each supporting modification, unforeseen delays will negatively impact the overall project, extending the time at risk. Thus, the ALARP argument for the modification must be viewed in terms of the wider hazard and risk reduction aim. The choice of fit for purpose solutions such as water jet cutting and off-the-shelf fire detection systems enable progress to be made, whereas the traditional approach would lead to prolonged delays while the infrastructure continues to degrade.
- **Balance of emphasis duty holders place across the various engineering and administrative facets of a multifaceted defence in depth hierarchy**
  In order to control the increase in risk brought about by these intrusive modifications, a change in emphasis is often required. For instance, the adjusting of operating rule to allow for increased oxygen level signals a switch in focus from prevention of ignition to prevention of fire propagation. There is also a greater reliance on operator intervention to control risk since designing fully engineered systems for every modification would require an unacceptable delay. Other mitigating measures have been implemented such as enhanced emergency response systems.
- **Overall justification presented by the duty holders which demonstrates that the short term increase in risk is balanced by long term risk reduction.**
  Finally, the short term increase in risk for the facility overall, as well as the risk associated with the many supporting activities must be justified by balancing it against the wider objective of accelerated hazard and risk reduction. The duty holder - in this case Sellafield Ltd - must present their justification, in the form of a safety case, that the increase in short term risk is necessary so that the long term ALARP position can be met. It must be demonstrated that where there is an increase in risk it is because the only way to reduce the risk further would have an adverse effect on the wider risk reduction programme. Where additional risk has been accepted, proportionate measures must be put in place to ensure that the risk is reduced to ALARP while allowing for progress to be made.

Conclusion

The UK's nuclear legacy facilities present complex and pressing challenges for the industry. In particular, ONR must strike a balance to allow duty holders to achieve accelerated hazard and risk reduction while ensuring that standards with regards to safety are not lowered. By learning from previous experience, ONR has adopted an enabling approach in which it is recognised that in many cases there is no perfect solution and that some short-term increase in risk must be tolerated in order to address the long-term hazard before a serious incident occurs. By working with stakeholders towards a common goal, ONR will treat each modification on a case by case basis in order to find the balance that will enable the duty holder to make meaningful progress while ensuring that the necessary increase in short term risk is reduced to ALARP. The progress made in retrievals from Sellafield's Legacy Silos in recent years demonstrates how this balance can be achieved and serves as an early indication of the effectiveness of the enabling approach.

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