Nuclear Decommissioning Authority

Magnox Fuel Strategy

Contingency Options

January 2014

Contents

Executive Summary

The NDA strategy document of 2011 made a commitment to analyse contingency options for the management of the Magnox Operating Programme (MOP 9) inventory in the event of unexpected and irreversible failure of the Magnox reprocessing capability. This document summarizes the outcome of that analysis and presents the strategic position with respect to Magnox contingency arrangements.

In July 2012 the NDA published documents in which it re-affirmed its position that no case-for-change exists with regard to the Magnox strategy and it remains committed to the delivery of MOP 9. Within these documents, however, the NDA highlighted that completion of reprocessing of the MOP inventory carried risk. Accordingly the NDA has been working with Site Licensees and Regulators for a number of years to develop a range of contingency options capable of managing the MOP inventory on an interim basis should the unexpected occur.

The contingency options identified and taken forward, and the logic underpinning their development, have arisen from examination of a range of credible ‘failure’ scenarios, the quantity and location of unreprocessed fuel at the point of failure, plus the circumstances in which contingency plans can be deployed. To provide appropriate coverage to the wide range of possible outcomes considered it has been necessary to focus attention on three key areas:

1. the development of fuel drying and dry storage technology
2. the case for extended interim wet storage
3. the case for extended in-reactor storage.

The progress made in these areas has been significant and all are considered feasible options capable of contributing to the safe interim management of spent Magnox fuel should reprocessing capability be irreversibly lost. The development of drying technology to manage the wetted portion of the MOP inventory, in particular, is at an advanced stage, and there is high confidence that this option is deployable if required. Similarly, there is high confidence that the safety case for extended in-reactor storage can be made and implemented where necessary. Extended interim wet storage, by comparison, is less mature, in-line with the expectation that this option could serve as an ‘enabling’ technology. For each of the options presented further effort is required to: accelerate the deployment timescales of the vacuum drying contingency, underpin the acceptable wet storage timeframe of Magnox, and formalise arrangements with respect to the in-reactor storage management requirements.

Investment in these activities is at a level commensurate with the level of risk associated with the successful completion of the MOP itself and those risks present in the wider NDA estate. An annual review of the delivery performance of the MOP and the status of the Magnox strategy will be undertaken starting March 2014.

1 Magnox Strategy and the Magnox Operating Programme

The Magnox reactors were the first generation of nuclear power stations to operate in the UK, and responsibility for their decommissioning was assigned to the Nuclear Decommissioning Authority on 1st April 2005. In the UK, between 1956 and 1971, 11 power stations were connected to the national grid comprising 26 reactors. Magnox reactors are graphite moderated, CO_2 cooled, and use Magnox-clad uranium elements that were manufactured at the Springfields site in Lancashire. Following irradiation and short-term storage at the reactor sites, spent Magnox fuel is transported to the Sellafield site where it is reprocessed. The Magnox Reprocessing plant at Sellafield became operational in 1964.

Completion of Magnox reprocessing operations as soon as reasonably practicable, using the existing assets, continues to be the NDA's preferred strategic option for the management of the MOP inventory. The NDA recognises, however, that there are risks to completion of the programme and has worked with Site Licensees and Regulators to explore and develop a range of fallback options.

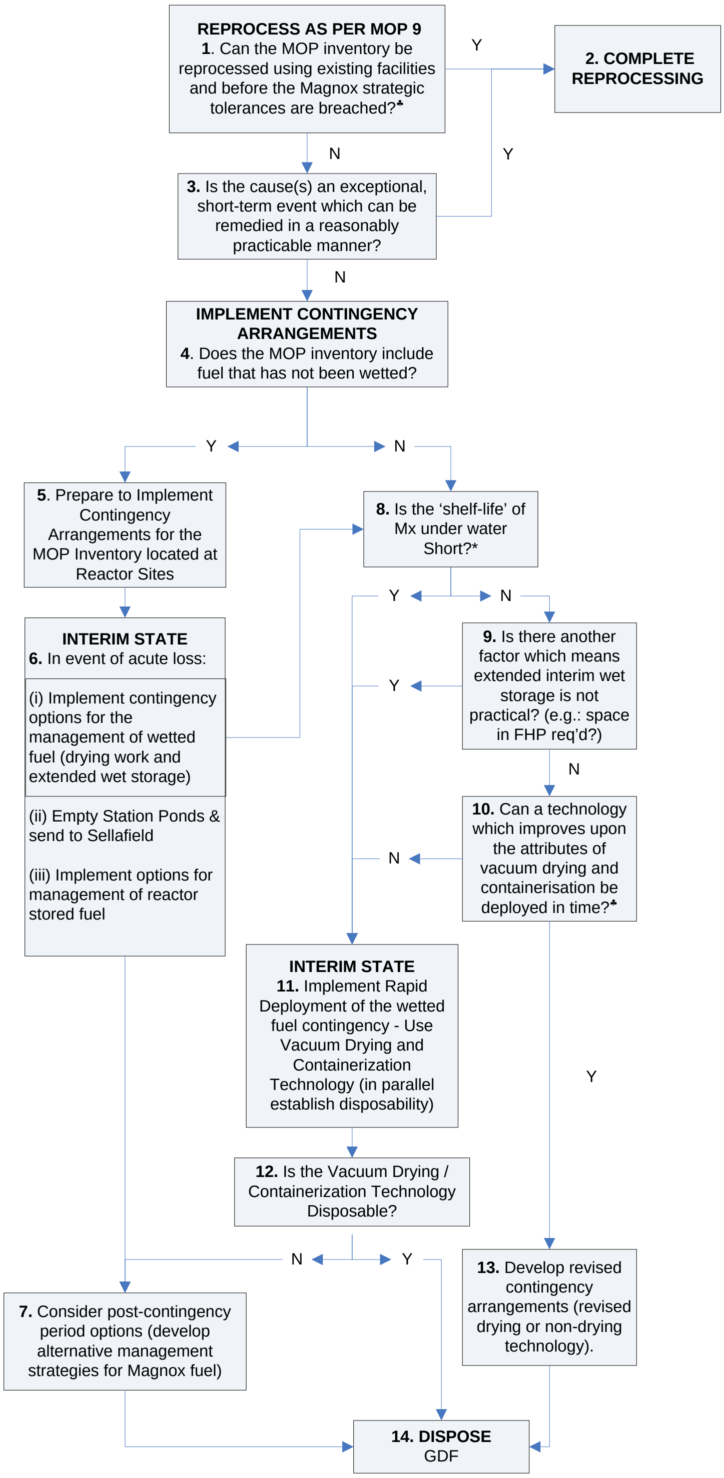
The Magnox Operating Programme (MOP 9) and Magnox Strategy have recently been updated and published in July 2012 [1, 2]. As of March 2013, approximately 3500 tU of spent Magnox fuel remains to be reprocessed [3] out of a total of ~50,000 tU manufactured and irradiated. Approximately 2650 tU of the spent Magnox fuel is held in-reactor with the rest (~850 tU) in interim wet storage in ponds located at the reactor sites and Sellafield. The MOP inventory also comprises ~40 tU of DFR breeder material. 3500 tU of irradiated Magnox equates to ~300,000 individual elements and is a significant amount of fuel. If average MOP performance levels can be maintained or exceeded, the MOP inventory is anticipated to have been reprocessed *circa.* 2018-2020.

The primary focus of this document concerns the interim management options for spent Magnox fuel upon sudden irreversible loss of reprocessing capability (often termed acute loss) and therefore does not consider full lifecycle management. Should acute loss of the Magnox reprocessing capability occur there will be little warning of failure and minimal opportunity for managed intervention. Where the loss of reprocessing capability occurs gradually (termed chronic failure), there are likely to be more options to manage the quantity and location of the inventory holistically so that the lifetime liability is minimized.

Ultimately the amount and type of spent Magnox fuel to manage, and the contingent technology that can be deployed, will depend on the timing and mode of failure. Factors that are likely to influence decisions involving contingency arrangements include:

- the amount of fuel to be reprocessed
- the location and condition of the fuel involved
- the mechanism by which reprocessing operations cease
- the availability of other facilities at Sellafield (and at other locations)
- the time required to deploy a contingency option
- the interim storage regime
- the extant transport regulations at the time of acute failure.

Figure 1 presents the high-level logic used to define and develop the contingency options presented within this document.



♣ = strategic tolerances (inter alia discharges/critical assets and infrastructure/lifetime cost and afforability/technology readiness of other technologies etc), * = of a duration which is less than industry norms

Figure 1: A high-level logic diagram illustrating the areas for consideration in the event of unexpected and irreversible loss of the Magnox reprocessing stream.

Figure 2 is a schematic illustration of how the quantity and location of spent Magnox fuel could vary with time. A range of throughput levels are presented (drawn as lines having differing gradients and corresponding to 740, 600, 450 and 250 tU reprocessed per annum). When rates of reprocessing are high, the rate at which the quantity of fuel decreases is significant thereby bringing the predicted end-date of the MOP closer. The quantity of fuel, reactor-by-reactor, is presented in block-form to the right. Chapelcross completed defueling in February 2013 (white box signifying the reactors are empty) thereby leaving just 3 reactor sites (Sizewell, Oldbury and Wylfa) plus the Calder Hall reactors holding fuel. Calder Hall and Wylfa are presented as being full, while Sizewell A and Oldbury are shown to be defueling. Clearly, while reprocessing operations continue the quantity of fuel within the reactor cores falls so that, one-by-one, the number of reactor sites holding fuel decreases. Total wet storage capacity is presented as being ~1000 tU, and the current operational capacity of fuel handling plant pond at Sellafield shown to be fractionally less (~850 tU).

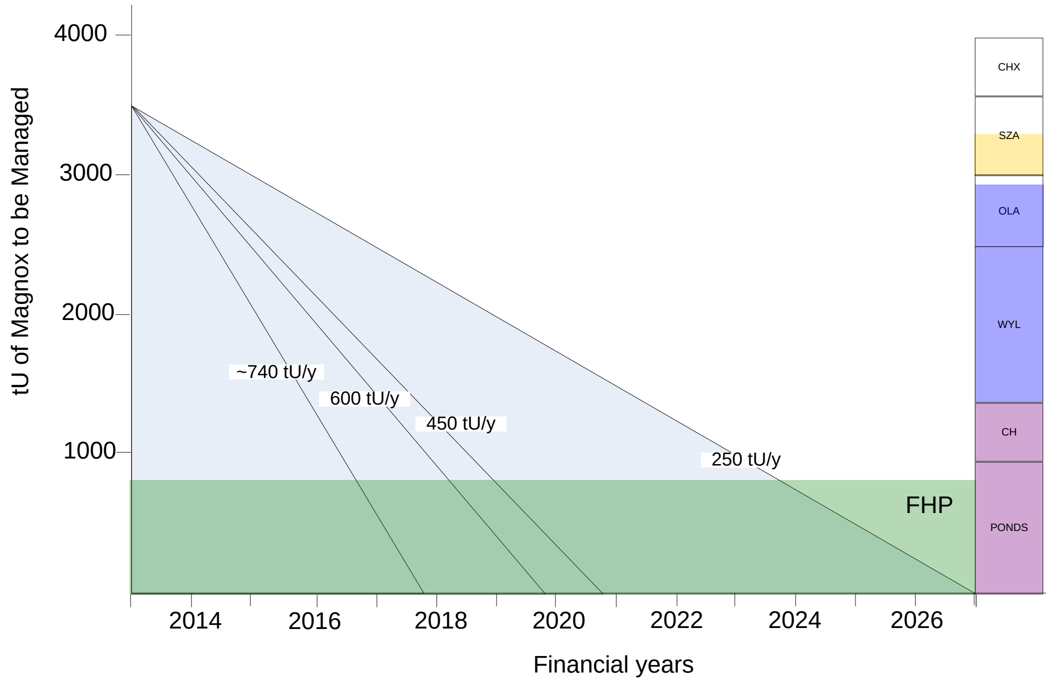


Figure 2: Schematic illustration of the quantity and location of Magnox fuel as a function of MOP performance (CHX: Chapelcross, SZA: Sizewell A, OLA: Oldbury, WYL: Wylfa, CH: Calder Hall

Ultimately, only Calder Hall and Wylfa will contain fuel with the consequence that Sellafield will be the only location in which wetted fuel is stored. When Wylfa is defuelled the entire MOP inventory will be interim stored at Sellafield awaiting reprocessing and is likely to comprise almost entirely wetted fuel. The exact ratio of dry to wet fuel as reprocessing continues will be optimised according to prevailing circumstances. A non-exhaustive list of the factors likely to affect the dry-to-wet ratio will be the amount of fuel in the inventory, the reprocessing throughput rate, the capability of the transport facilities, and the perceived level of risk associated with MOP completion. Assuming the limits on wetted pond stocks remain approximately constant, in the coming years the dry to wet ratio should steadily decrease from the 4:1 value presently observed.

2 Contingency Options for Managing Spent Magnox Fuel

Historically a diverse range of technologies for the management of unreprocessed spent Magnox fuel have been examined including the use of existing facilities such as THORP, Magnox encapsulation plant, plus others. A review of previous assessments has been undertaken in order to confirm the continued validity of the original assessments. These reviews verified that under the present circumstances, the number of credible contingency options for managing spent Magnox fuel in the event of irreversible loss of reprocessing capability are limited. As discussed in the July 2012 Magnox Strategy Paper there are two high-level contingency options for managing the MOP inventory on an interim basis: interim dry storage or interim (but extended) wet storage [2].

2.1 Interim Dry Storage

Dry Fuel

At the time of writing the bulk of the Magnox inventory (~75%) is located in-core at reactor sites, and has not been wetted. Options on how best to dry store fuel currently held at reactor sites have been considered on a number of occasions. The NDA in combination with Site Licensees, has reviewed previous work with a view to understanding whether any new opportunities have become available as a result of technological advances, and/or the reduced mass of fuel requiring to be managed.

Options considered included centralized storage at locations away from reactor sites, localized new storage at reactors sites or in-reactor storage. A range of discriminatory factors were considered which, when collated, indicated that interim dry storage of spent Magnox fuel in-reactor as being optimal. An in-depth study of the in-reactor storage case at the Oldbury and Wylfa sites (which are likely to be the only reactor sites external to Sellafield holding fuel by 2016) was subsequently completed and indicated that storage periods of many decades are achievable. Revised arrangements for maintaining reactor conditions, defueling the reactors following extended fuel storage, and onward management would need to developed and deployed but all were considered feasible.

Although not formally part of contingency arrangements, the timing and nature of the 'conditioning' step following in-reactor storage was also examined. Post-interim storage conditioning can be expected to be determined, *inter alia*, by a range of factors such as location of the reactor site, the effectiveness of the storage regime applied, the status of the technology used in the Sellafield decommissioning programmes, future transport regulations and the availability of geological disposal facilities (GDF), *etc*.. In theory, it could occur shortly after the removal of fuel from the reactor (within a 1-20 year timeframe) or at the point where the fuel is about to be transported to the disposal facility.

Wet Fuel

Under the conditions of acute failure it is anticipated that wet stocks levels up to ~1000 tU may need to be managed. Presently it is assumed that any residual wet stored fuel would require transition into dry storage. A number of options to transfer wetted Magnox fuel into dry storage have been considered.

Of these, the Magnox vacuum drying technology, which is based on techniques that were used to manage wetted fuel at the Hanford Site in the United States, is most developed. The MOP drying contingency work was initiated as a study by the NDA in 2007 before transferring into the Spent Fuel Management Business Directorate at Sellafield in 2009. In March 2011, the project team demonstrated that the vacuum drying process could be used to dry ~98+% of the wetted MOP inventory. At that time the deployment timeframes for the plant was anticipated to be ~4.5-6.5 years, with a further ~2-3 years being required to dry and containerize the inventory. Since 2011, rapid deployment options have been explored and the anticipated timeframes to deployment reduced.

2.2 Interim Wet Storage

The in-pond storage of spent Magnox fuel for extended periods (>10 years) has not been the subject of significant attention historically. Typically, spent Magnox fuel has only been held in-pond for relatively short periods prior to being reprocessed. As a result, data in support of Magnox wet storage are limited and have tended to focus on underpinning timeframes of 5-6 years. While the Sellafield reprocessing facilities remain operational the 5-6 year timeframe is sufficient to allow the logistics of transport, fuel blending, plant maintenance activities *etc.*, to be progressed unhindered.

On the basis of the current storage regime, inventory and performance assumptions, it is considered that wet storage of the entire Magnox inventory (currently ~3500 tU) would not present a credible approach for long-term management of spent Magnox fuel. Although no decision has been made that would foreclose options, it is assumed unlikely that construction of new wet storage capacity would be considered tenable under the present circumstances. It is also assumed unlikely that fuel which has not been exposed to water previously will be subsequently wetted where it is likely to require levels of active management over and above those required for in-reactor storage.

While wet-storage followed by conditioning and disposal, based on the current information, is not being proposed as a credible fallback option to reprocessing operations the NDA continues to support additional work on wet storage. This is because there is some evidence to suggest the present assumptions on wet storage may be unduly conservative and that there may be benefit in exploring whether it is possible to extend the interim wet storage time available. Principally this is to mitigate the effects of an extended wet storage period on fuel condition pending implementation of the fuel drying/dry storage technology. However, it may also enable other technologies capable of treating wetted Magnox fuel to be developed or adopted, which could reduce the liability to the taxpayer. An example being the fuels and waste solids management technologies currently in development in support of Legacy Ponds and Silos remediation. NDA is monitoring the development of such technologies and their potential application to the Magnox strategy.

Preliminary assessments by Sellafield Ltd, supported by independent experts, suggest wet storage durations in excess of 10 years is technically possible under some conditions however a fully developed safety case has yet to be made. Additional research is thus underway to develop further the basis for extended interim wet storage of spent Magnox fuel so that the timescales on which contingency options are required to be implemented can be better defined. To that end, a preliminary programme of activities comprising on-plant measurements, laboratory-based research and theoretical studies has been initiated.

3 Key Risks and Uncertainties

There are a number of uncertainties associated with the interim dry storage and interim (but extended) wet storage contingency options which require further evaluation.

The key areas for interim dry storage are:

i) the extent to which wetted fuel stocks have been reduced before reprocessing of spent Magnox fuel ends
ii) the quantity and location(s) of dry fuel requiring in-reactor management
iii) timescales for implementation of the drying capability
iv) the duration of interim dry storage
v) the identification and development of conditioning step(s) to produce package(s) suitable for disposal following interim storage
vi) future transport regulations and transport infrastructure
vii) the suitability of steel pressure vessel reactors for extended in-reactor storage

The key areas for interim wet storage are:

viii) the quantity of wetted fuel requiring management
ix) the duration of interim wet storage prior to conditioning
x) the robustness of wetted storage to external factors (site infrastructure, spent oxide fuel strategy, use of plant for storing other materials *etc*.)
xi) the identification of a conditioning step to produce a package suitable for disposal following interim storage
xii) timescales for implementation of the conditioning capability

Items (i), (ii) and (viii) are directly related to the ongoing delivery performance of MOP 9. Where throughput performance is good, the rate at which the dry inventory diminishes is significant and pond stocks should remain relatively high in order to provide adequate bufferage for transport and reprocessing operations. Where performance is lower than predicted the rate of defueling from the reactors, and therefore the wetted pond stock, will be dictated by the circumstances at that time.

Items (iii) and (xii) are controlled by a range of interdependent factors (such as the status of the developed technology, availability of human resources, supply chain capability, commercial and financial arrangements *etc*.). In the event of sudden irreversible loss of Magnox reprocessing capacity it is anticipated that every reasonably practicable effort would be taken to minimise contingency deployment timeframes. With this in mind work continues on the early development of technologies and plant, delivery options for equipment *etc*. in order to facilitate rapid deployment should it be required.

Items (iv), (vii), (ix) and (x) relate to the period of interim storage. In developing contingency options for both dry and wetted portions of the MOP inventory the approach that has been adopted is one where, as a minimum, the period of interim storage is sufficiently long so as to allow technology to be developed/deployed without the fuel undergoing significant deterioration (such development/deployment timeframes are frequently called *norms* and can be of the order of ~10 years for large scale, one-off projects). For dry storage options it is anticipated that fuel will be capable of being interim stored for many decades. It is likely therefore that the dry storage period will not be determined by fuel degradation but by a range of other external factors (phasing of other high priority programmes, availability of disposal facilities, access to conditioning plant (if required) *etc*.). For wetted fuel the acceptable storage timeframe is currently less than the Sellafield norm, hence the vacuum drying programme is already underway and, being supplemented by parallel studies which are expected to confirm wet storage durations in the region of 10+ years are feasible.

Items (v), (vi), (ix) and (xi) will be affected by the underpinned interim storage period for Magnox under wet and dry conditions plus the phasing of other high priority programmes, availability of disposal facilities, access to existing conditioning plant *etc*. For contingency development purposes the primary focus is the near-term stabilisation of the fuel for an interim period. Consideration of how to make a disposable package is a secondary factor although RWMD have undertaken provisional assessments of the vacuum dried, containerised Magnox fuel package. Additionally the NDA maintain pro-active oversight of other technologies capable of managing the MOP inventory.

4 Implications of Deploying Magnox Contingency Technologies

4.1 Economics

An economic assessment of the Magnox contingency options has been undertaken and is presented (figure 3) in general terms. These high-level comparisons have been developed using data from a range of sources and, by necessity, rely upon a range of assumptions which can impact significantly upon the final ‘cost’ calculated. In presenting these figures the NDA aims to provide a sense of the level of resource required to manage the MOP inventory should reprocessing operations cease.

For illustrative purposes, a number of scenarios have been developed based upon the loss of Magnox reprocessing at anytime between now and March 2020. A 20-year interim storage period at reactor sites and a generic ‘black-box’ processing plant which processes fuel over an arbitrary ten year period prior to eventual disposal (disposal costs are not included to allow comparison with the extended reprocessing scenarios) has also been included.

Figure 3 shows the relative cost of reprocessing with time when compared to fallback technologies. The relative cost (excluding disposal) of acute failure of the MOP is considerable and is a factor informing the NDA’s preference to see Magnox reprocessing operations complete as soon as reasonably practicable. Cost is observed to reduce markedly with time as the number of fuelled reactor sites decrease. The key contributory factors to 'costs' include expenditure resulting from continued management of existing facilities and the requirement to manage - on potentially short timescales - the issues associated with Magnox fuel stored within ponds at reactor sites and Sellafield while simultaneously storing fuel still left in the reactor cores.

4.2 Existing Strategies and Delivery Programmes

A requirement to deploy contingency technologies at Sellafield and fuelled reactor sites is considered likely to have an impact upon the progression of existing lifetime plans.

At the reactor sites the transition from being fuelled to defueled, through to commencement of decommissioning, will be delayed and certain to have implications to safety and security arrangements, the skill-set of the workforce, and the local communities.

At Sellafield the deployment of contingency plans would represent a significant change in the Magnox strategy and would have the potential to impact upon a number of other NDA strategies and delivery programmes. For example, the Magnox Strategy has direct linkages with the following areas:

- Plutonium
- Oxides
- Uranics
- Exotic Fuels
- Asset Management
- Revenue Optimisation
- Higher Activity Wastes
- R&D and Skills

In a number of respects the implications of developing contingency options for the management of irradiated Magnox fuel have had positive benefit. The vacuum drying technology, for example, which was being developed as part of the MOP contingency programme, is being developed with a view to providing opportunities for early management of materials held within Legacy Ponds and Silos (LP&S) at Sellafield. Equally the work to underpin in-reactor storage at the reactor sites has prompted examination of in-reactor storage regimes during defueling with a view to ensuring options for extended storage are not unintentionally foreclosed.

5. Conclusions

In recognition of the risks associated with completion of the MOP, the NDA has worked with Site Licensees and Regulators to explore and develop a range of contingency options. Significant progress has been made in recent years to strengthen the interim management arrangements for the MOP inventory in the event Magnox reprocessing capability is lost unexpectedly and irreversibly. Three principal areas have been taken forward to manage the wet and dry portions of the MOP inventory and there is high confidence that contingency arrangements can be deployed if required.

To improve confidence further, investment in these areas will continue at a level commensurate with the level of risk associated with the successful completion of the Magnox Operating Programme itself and those risks in the wider NDA estate.

6. References

[1] *Strategy*: Published by NDA, March 2011
[2] *The Magnox Operating Programme (MOP 8)*, Rev 2: Published by NDA, Jan. 2009
[3] *The Magnox Operating Programme (MOP 9)*: Published by NDA, June 2012

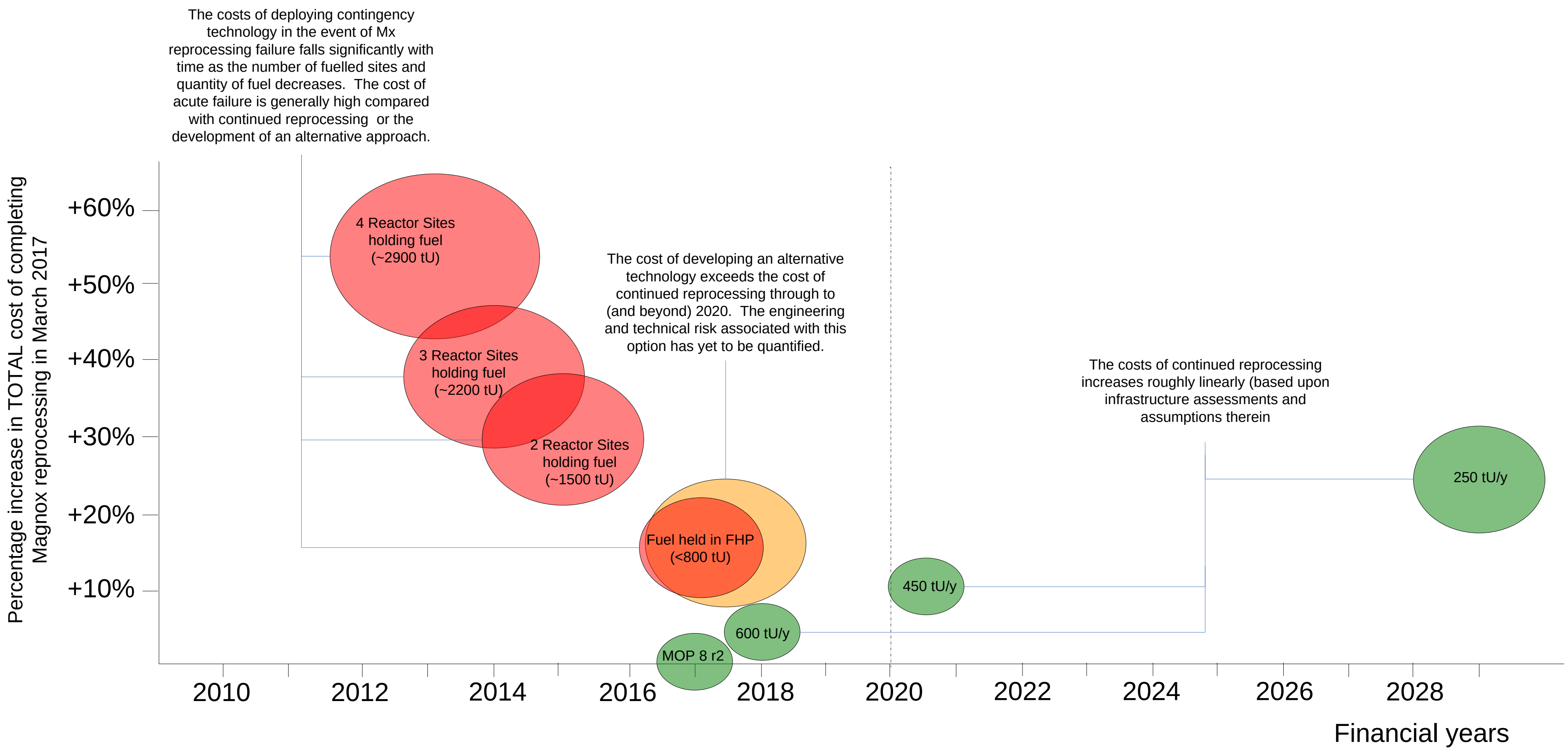


Figure 3: Graphical Representation of the High-level ‘costs’ associated with continued reprocessing and development and deployment contingency plans