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EFFECT OF ORIGINAL MANUFACTURING DEFECTS/OPERATIONAL WEAR ON OLDER PACKAGES SAFETY REPORTS

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ABSTRACT

MOPDT (Magnox Operating Programme Delivery Team) are responsible for the safe delivery of irradiated fuel from the remaining fuelled Magnox Ltd sites in the UK and Dounreay (Scotland) site to the Sellafield reprocessing facility. The fuel is transported in a fleet of 42 Type B(M) cuboidal transport flasks (referred to herein as M2 flasks), the transport of which is regulated by the ONR-RMT (Office of Nuclear Regulation, Radioactive Material Transport). Approximately 7-8 flask transports are completed in a typical week. The current Magnox Operating Programme, which defines Magnox sites generation and defueling periods, predicts that fuel shipments will continue until around 2019.

This paper looks at the effect original manufacturing defects/operational wear in older packages can have on the Package Design Safety Report when identified using more modern inspection techniques than those used during original manufacture. In particular, a recent case study to justify sub surface indications in the cooling fin to main body full penetration welds will be referenced. This work package involved ultrasonic inspections (not utilised during original manufacture), structural integrity and thermal finite element analysis exploring the effect sub surface indications in the cooling fin welds have on the M2 flasks performance during normal transport and the regulatory accident conditions. Based on the conservative assumption of complete loss of a number of cooling fins, the defects have been justified through analytical calculations of normal transport conditions and producing evidence of flask performance during the regulatory accident. This work has increased knowledge in the effects of definning and the levels of redundancy within the M2 flask design.

The final area of this paper looks at how Magnox Ltd is currently taking a pro-active approach to highlighting potential engineering challenges within an ageing flask fleet. This has included a thorough independent review of the flask design and history, concluding in further on-going work packages, for example reviewing original manufacturing/inspection records, determining rate of thread wear and strategic procurement of spares.

Conclusions will be drawn to support recommendations for modern RAM transport package design, assessment, operation and maintenance to mitigate as far as practicable the risk of original manufacturing defects/operational wear, identified through modern inspection techniques, challenging the on-going use of the package.

1 INTRODUCTION

MOPDT are responsible for the safe delivery of fuel from the remaining fuelled Magnox Ltd sites and Dounreay site in the UK to the Sellafield reprocessing facility. The irradiated fuel is transported in a fleet of 42 Type B(M) cuboidal transport M2 flasks, the transport of which is regulated by the ONR-RMT (Office of Nuclear Regulation, Radioactive Material Transport). The current Magnox Operating Programme, which defines Magnox sites generation and defueling periods, predicts that fuel shipments will continue until around 2019.

MOPDT hold copies of all relevant manufacturing records (the flasks were manufactured in the mid 1980s) and all in service records. These records are used to support claims made in the Package Design Safety Report (PDSR), justifying the design and operation of the flasks in accordance with the International Atomic Energy Agency (IAEA) transport regulations.

When justifying the operation of older packages, there are unique challenges posed; for example, justifying the level of in-service wear and producing current arguments based upon documentary evidence from original manufacture.

This paper looks at the effect original manufacturing defects in older packages can have on the PDSR if identified using modern inspection techniques. In particular, a case study on recent work to justify latent sub surface indications in the cooling fin to main flask body full penetration welds will be referenced.

The final area of this paper looks at how Magnox Ltd is currently taking a pro-active approach to highlighting potential engineering challenges within an ageing flask fleet.

2 CASE STUDY: FIN WELD INDICATIONS

It is highlighted that the case study on fin weld indications is currently being reviewed by the Competent Authority for the UK (the Office for Nuclear Regulation – Radioactive Material Transport). As such, the approach and views within this paper are those of Magnox Ltd alone and do not currently form part of the approved transport case.

2.1 Flask geometry and maintenance background

The M2 flask is a cuboidal flask, with 42 cooling fins around four sides. The fins are attached to the flask body by full penetration welds using either Manual Metal Arc or Submerged Arc Welding techniques or a combination of the two. The majority of the fins are 1 inch thick.

There are two valves on the flask; a lid valve used to vent or dose the flask and a water level valve used to confirm the level of dosed water prior to transport on the side of the flask. There is also a double seal arrangement between the flask lid and flask body. The lid is retained by 16 lid bolts.

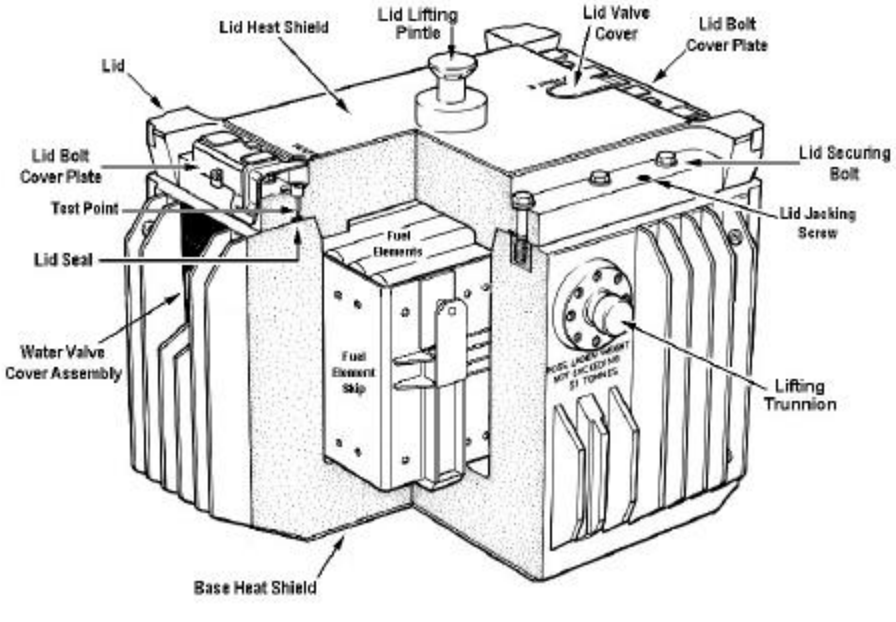

Figure 1 General arrangement of an M2 cuboidal flask highlighting key features.

The M2 flasks are maintained on a 3 yearly basis. A significant part of the maintenance is the grit blast removal and subsequent reapplication of the paint.

Due to the repeated grit blasting and improved inspection regimes, some minor gas pores have become exposed on the flask body surface. When paint is applied over the gas pores, capillary action during paint drying causes pin holes in the surface finish of the paint. It has been highlighted that these pin holes could hold a small amount of contaminated water (from flask ponding) that could subsequently drain during transport. Due to this risk, the flask is inspected following painting and any pin holes/imperfections are reported and investigated.

2.2 Identification of indications

During maintenance of a flask an indication was identified on the bottom surface of a cooling fin, within the weld area. Controlled grinding, etching and Magnetic Particle Inspection (MPI) was undertaken on the indication and a materials specialist concluded the indication appeared to be lack of fusion from original manufacture, see Figure 2.

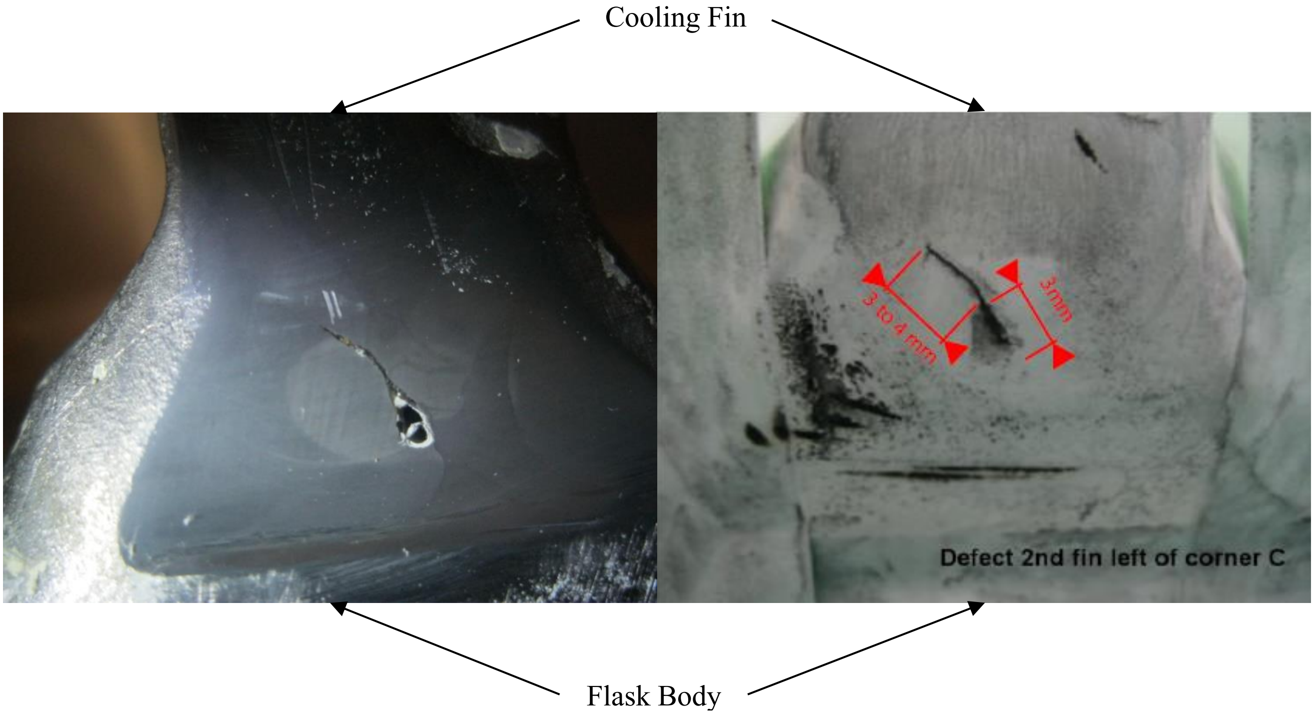

Figure 2 Indication identified on the bottom of a cooling fin following polishing (left) and MPI (right).

The predominant welding technique used for attachment of cooling fins across the fleet was Submerged Arc Welding. Due to the semi-automatic nature of this welding technique, it was hypothesised that the lack of fusion indications could have significant length in the direction of the weld.

A review of the original manufacturing records identified that ultrasonic inspection of these welds had not been undertaken; the welding technique was proven through completing test welds and undertaking destructive sectioning of the test welds to prove adequacy. This approach was appropriate given that the welds do not form part of the pressure boundary of the flask.

Due to the absence of previous sub surface inspections, ultrasonic testing was undertaken on the flasks in maintenance. The procedure and technique sheet developed were assessed to determine the capability of the inspection.

The results supported the predictions, in that a number of pattern 1 indications (no significant through wall dimension) with significant length along the fin were identified. These inspections were completed on a population of fins across a number of different flasks, the majority of which showed similar results.

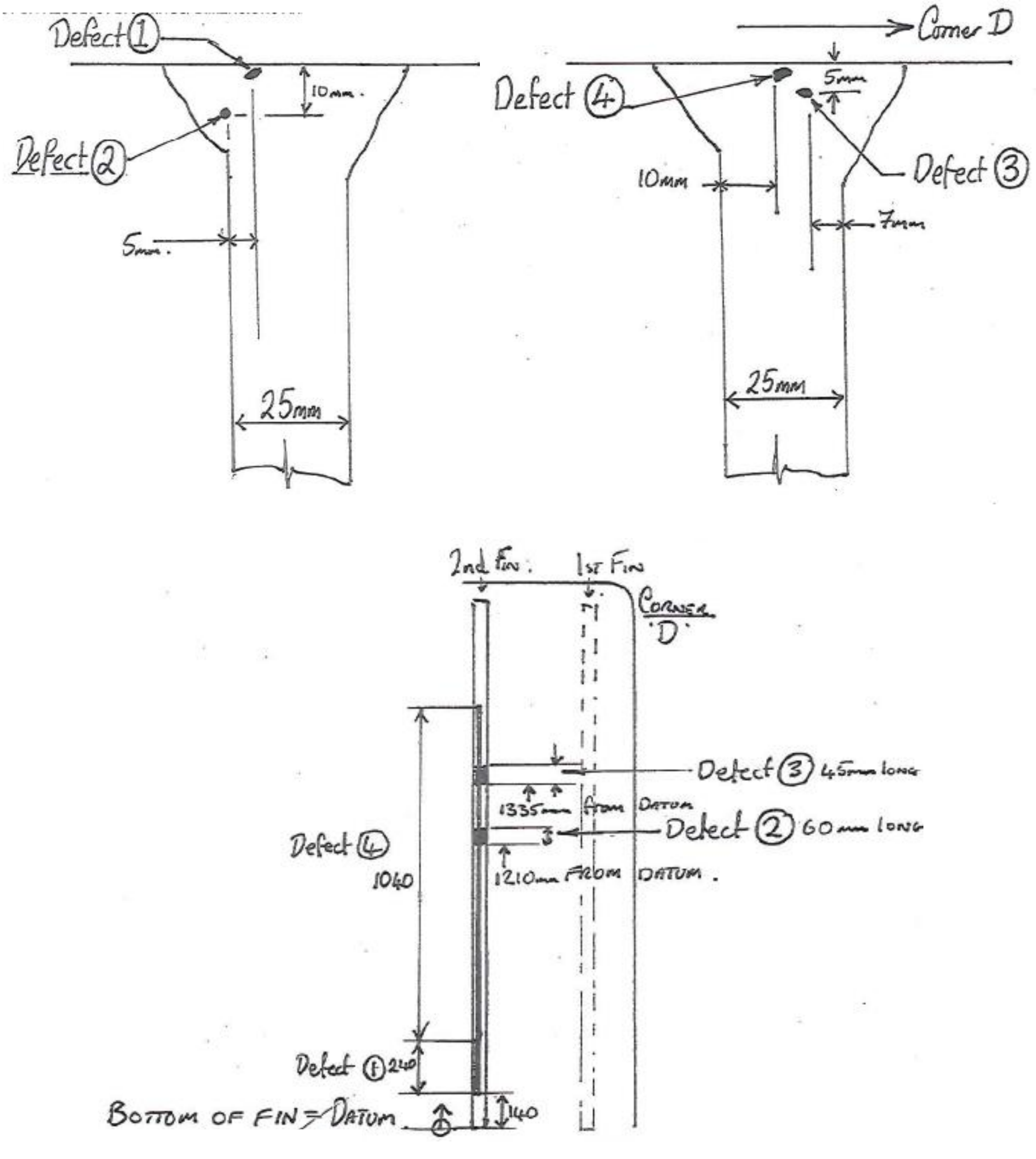

Figure 3 Example ultrasonic inspection results.

2.3 Effect on safety case

The following areas of the PDSR were considered to be affected by the presence of defects in the cooling fin to flask body weld.

1. Thermal assessments during normal transport and accident conditions – presence of defects could challenge the heat transfer rates potentially leading to increased peak flask temperatures.
2. Structural integrity assessment during 9m drop – presence of defects could cause detachment of cooling fin(s) from the flask, which could lead to increased peak flask temperatures during the regulatory fire scenario.

Due to the potential for increased peak temperatures, the following secondary challenges were also highlighted:

1. The performance of seals.
2. The thermal stresses in welds between dissimilar materials.
3. The assessment of worst case drop orientation within the PDSR.
4. The rate of uranium/Magnox corrosion, and hence the pressure build up within the flask leading to activity release rates.

This case study provides a strong example of how previous oversights on defect acceptability can become embedded within significant sections of a PDSR.

2.4 Proposed justification

2.4.1 Normal transport – thermal assessment

To determine the effect of the indications on the thermal assessment during normal transport, a pessimistic 2D thermal model was produced based upon the following assumptions:

1. No heat transfer over 50% of the flask/fin weld thickness (to pessimistically model the thermal resistance caused by the indications).
2. No credit claimed for the weld fillet profile (to allow use of analytical conformal transformation solution whilst remaining pessimistic).

The 2D model used and resulting temperature contour plots are represented below.

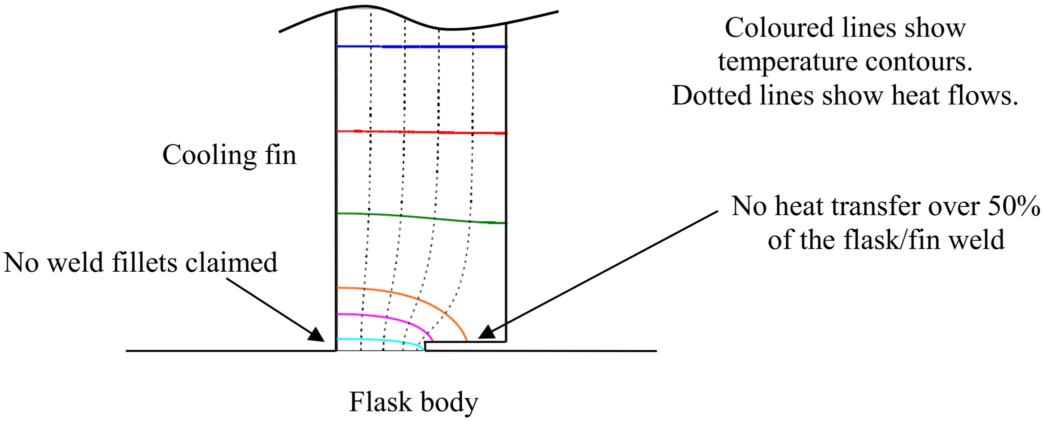

Figure 4 2D model and results of flask/fin cooling fin used for modelling normal transport thermal assessment.

The overall consequence has been calculated to be a 0.36°C increase in overall flask temperatures during normal transport during worst case conditions (i.e. highest heat load carried, maximum ambient temperatures).

This is an insignificant rise derived from overly pessimistic assumptions and is still less than other unclaimed conservatisms within the PDSR, thus it was concluded all existing assessments within the PDSR remain bounding.

2.4.2 Accident conditions (fully finned) – thermal assessment

The indications identified by ultrasonic inspection will impede the heat dissipation of the flask following the thermal accident conditions. However, the indications will also impede the heat absorption of the flask during the fire. The rate of heat transfer is significantly larger during absorption in the fire compared to dissipation after the fire. As such, it is judged that the slightly higher initial seal temperature will be more than offset by the heat transfer impairment that occurs during the fire. Consequently, it is concluded that the peak lid seal temperature that occurs as a consequence of the regulatory fire would not exceed those currently assumed within the PDSR assessments.

2.4.3 Accident conditions (fully finned) – structural integrity assessment

Initially, the approach was to justify that the cooling fins remained attached to the flask during the 9m drop despite the indications identified. This would then allow all further assessments within the PDSR to remain unchallenged (as all assessments assume attachment of cooling fins).

A review of the supporting drop tests within the PDSR found that there were no drop angles seen to represent the worst case loading onto a single fin. As such, an alternative approach using the R6 defect assessment procedure was utilised to determine whether a fin would bend or fracture during excessive loading.

Based on the capability assessment of the ultrasonic inspection technique, all indications were assumed to be 7mm in length, despite the fact that all indications were pattern 1 (i.e. no measurable through wall depth). This is because the through wall thickness had to be assumed to be the same width as the beam spread, 7mm.

Additionally, the root cause of the indications had been identified as lack of fusion (either root or inter-run). Therefore the structural assessment had to account for the indication potentially having sharp tip stress raisers at the most pessimistic orientation.

The resulting defect acceptance criteria were used to justify return to service of a few flasks, however deficiencies in the approach taken rapidly became apparent:

1. A significant number of ultrasonic examinations of flask/fin welds would be required (to do a 10% sample would require ~180 inspections, each one requiring significant paint removal, a day’s worth of inspection and subsequent reapplication of paint).
2. Indications could occur at any point within the weld, yet the acceptance criteria could not justify indications near to the weld surface/away from the flask body due to the pessimisms required to account for limitations in ultrasonic inspection. Thus there was an on-going risk of identifying a flask that could not be approved through this process.

Due to the significant limitations detailed above, a broader justification approach was sought.

2.4.4 Accident conditions (loss of corner fins) – structural integrity assessment

The geometry of the flask, engineering judgement and the nature of the indications identified concludes that assuming loss of two corner fins during the 9m drop test would be pessimistic, with any further consideration becoming grossly pessimistic. Therefore, further thermal assessments were based upon the loss of two corner fins.

2.4.5 Accident conditions (loss of corner fins) – thermal assessment

In order to determine the effect of fin loss, a 3D finite element quarter and half model of the flask was created. The new model was first of all verified against the existing model within the PDSR through comparing results of comparative studies.

At this point the predicted fire scenario results were baselined and alternative scenarios representing all combinations of corner fin loss were run to produce comparative results.

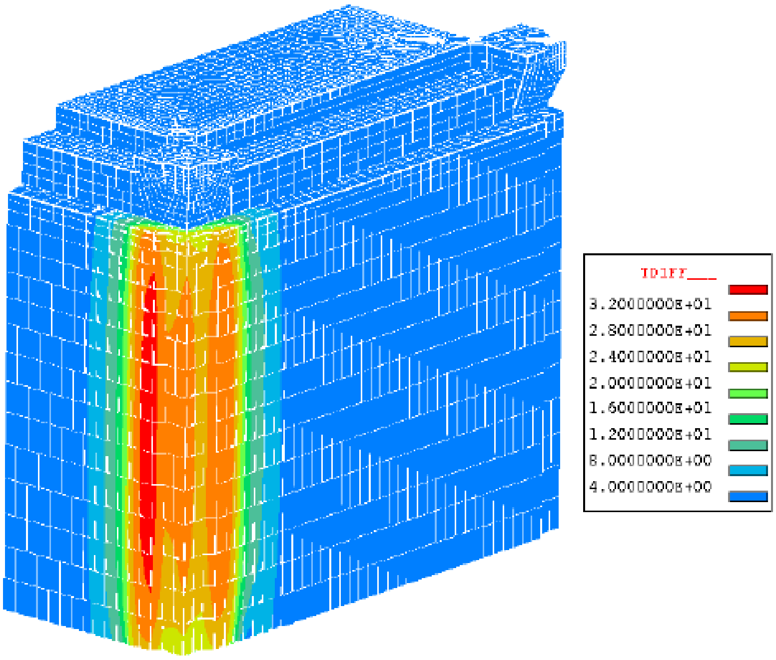

Figure 5 Half scale model results showing change in temperatures with 2 corner fins removed compared to baseline case immediately after 30 minute fire.

Although there were significant temperature increases on the surface in de-finned areas during the fire (as fins provide “shading” from the fire), the overall temperature increases in critical components of the flask were not large, as the components are set within the flask body.

Peak temperature increase ^{o}C relative to the fully finned case			
Lid seal groove	Lid valve	Water level valve	Flask contents
2.34	0.30	1.64	0.53

Figure 6 Peak temperature increases of all combinations of fin removal against the baseline case.

2.4.6 Accident conditions (loss of corner fins) – consequence of temperature increases

Having determined the pessimistic temperature increases due to fin loss, the following areas were further considered to justify the secondary effects to the PDSR previously identified in section 2.3:

1. Seal performance – justified through consultation with seal manufacturer and review of previous testing data.
2. Worst case drop orientation – justified that the worst case drop orientation considered in the PDSR is different to that required to cause fin removal, and that the drop orientation already in the PDSR remains bounding.
3. Thermal stresses – calculations repeated to reflect increased surface temperatures and confirm acceptability.
4. Activity releases – existing modelling results confirm insignificance of increased activity releases, based on representing increased temperatures through increased initial heat load within the flask.

2.5 Case study summary

The assumption of defect free cooling fin welds was found to have unintentionally become embedded throughout the assessments within the PDSR. The identification of indications that challenged this assumption required supporting justification which, given the age of the flask and assessment approach within the existing PDSR (proving performance only up to the regulatory limits) caused the scope of work to become enlarged.

However, the benefits of this work are greater than simply justifying continued compliance to the regulations of the M2 flasks. Magnox Ltd now possess a greater understanding on the flasks thermal performance during normal and accident conditions, in particular the level of redundancy within the cooling fin arrangement. Additionally, a large proportion of the work can be used to support the design review required by the IAEA regulations.

The case study emphasises the importance of acknowledging that rarely are manufacturing processes perfect and the need to prepare for this through development of justified defect acceptance based on the capabilities of inspection techniques. Secondly, there are significant benefits in understanding the abilities of a package above and beyond the regulatory requirements.

3 FUTURE MITIGATIONS

To further support continued operation of the M2 flask, MOPDT have also undertaken the following work packages, which will form the supporting evidence to a design review.

1. Independent review of flask design, manufacturing records and service histories to identify potential weaknesses/vulnerabilities in continued flask service/compliance.
2. Engineering review of all weld and thread fastenings to identify areas of increased risk (i.e. combination of consequence and likelihood), which is informing a review on condition assessment/recording during maintenance.
3. A gap analysis of manufacturing case histories in critical areas (e.g. main body welds) against modern fit for purpose standards.
4. Expert review of flask thermal and criticality assessments.
5. Procurement of life time and strategic spares to ensure quality of procurement when time pressures are not present.

4 CONCLUSIONS

This paper concludes that, based on recent Magnox Ltd experience, it is beneficial to:

1. Develop justified defect acceptance criteria during design, which can then be used to underpin inspection regimes and protect from minor issues identified post manufacture.
2. Understand the limitations on inspection techniques and further understand the implications this has on the assumptions made in subsequent calculations.
3. Understand a packages performance above and beyond the regulatory requirements; such that any subsequently identified minor deviations from the package design can be readily justified, without prolonged periods out of service.
4. Undertake continual reviews of the package, underpinning assessments, and manufacture/service records to ensure continued compliant operation, familiarity with the assessment techniques/models and also to allow quick recovery should any minor deviations from the design be identified.

Magnox Ltd are currently and plan to continue incorporating this learning in all aspects of the M2 flask operation and maintenance as soon as practicable.

It is highlighted that the case study on fin weld indications within this paper is currently being reviewed by the Competent Authority for the UK (the Office for Nuclear Regulation – Radioactive Material Transport). As such, the approach and views within this paper are those of Magnox Ltd alone and do not currently form part of the approved transport case.