FIRE TESTING OF A FULL SCALE WOOD FILLED FLASK SHOCK ABSORBER

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ABSTRACT
In many flask shock absorber designs, wood is used as the prime energy absorbing medium. Usually the wood sections are closely packed within a sealed steel casing with the grain orientation arranged to optimise impact performance. In large flasks over 1500kg of wood may be fitted.

Under IAEA impacts from 9m and the subsequent 1m punch test the sealed casing may split or puncture causing the wood to become exposed during the subsequent thermal test.

BNFL operate a number of flasks using wood filled shock absorbers and as part of a package safety development programme decided to conduct a thermal test on a typical example.

An NTL 11 flask lid shock absorber was manufactured to original specifications then 'modified' to represent impact damage. This was bolted to a heavy steel slab representative of the flask lid. This was fitted with thermocouples at salient positions and then the whole unit was erected in a fire test facility, where it was subjected to an all engulfing hydrocarbon fire lasting 30 minutes.
This test had two objectives:

1. To demonstrate the thermal protection given to vulnerable lid components during the thermal test
2. To assess the consequences of extended combustion of the wood material.

The test demonstrated that the lid shock absorber offered nearly total thermal protection to the lid during the fire, the temperature of the dummy lid rising by a few degrees. This was due to the wood remaining largely intact during the fire, a situation not normally assumed in the current analysis. This has demonstrated the inherent pessimism in the existing safety cases for BNFL packages which assume all the wood burnt away during the 30 minute fire.

The exposed wood in the shock absorber did continue to char for some time after the end of the thermal test but this was conclusively shown to have no adverse effect on the flask safety case.
BNFL consider this test was effective in demonstrating that boundary conditions applied during the thermal analysis gave pessimistic results.

INTRODUCTION
British Nuclear Fuels plc (BNFL) own five NTL 11 type flasks for the transport of irradiated LWR fuel assemblies. These have been operated successfully since their introduction in 1977 on shipments from European utilities to reprocessing plants at La Hague in France and Sellafield in the UK.

In 1998 BNFL decided to update these flasks by introducing a number of proven features adapted from more recent flask designs. This work would be carried out in conjunction with a complete revision of the package safety case.

Modifications to the NTL 11 flasks were significant and included revised trunnion attachments, new fuel support frames, additional neutron shielding and new designs of wood filled lid and base shock absorbers. The latter supersede aluminium plate types that had been fitted since the flasks were first introduced. The new shock absorbers also included an up-rated attachment system giving improved retention strength under impact conditions.

DESIGN VALIDATION

Impact protection provided to the NTL 11 flask by the new wood filled shock absorbers was proven by five sequences of drop tests on third scale models. Each sequence of tests including an impact from 0.3m height followed by one from 9m and finally a punch penetration test from 1m height. Five drop orientations were tested during which the shock absorbers demonstrated excellent performance in protecting the flask, the new attachment system proved particularly efficient.

However a potential outcome with this type of shock absorber during impact testing is to expose wood by local fracture of a welded joint in the steel casing and/or by a hole caused by punch penetration. This occurred during the NTL 11 drop tests when a lid corner impact caused a welded joint at the impact point to split and a subsequent punch aimed at the lid vent orifice penetrated the steel casing and indented the wood.

Under large plastic deformations, local cracking of welded joints in a shock absorber casing is not uncommon and results in negligible reduction in impact performance.

SHOCK ABSORBER DESIGN

A brief description of the lid shock absorber design is given below; the general design philosophy applies to both lid and base end shock absorbers.

A schematic view of the lid shock absorber is given in Figure 1

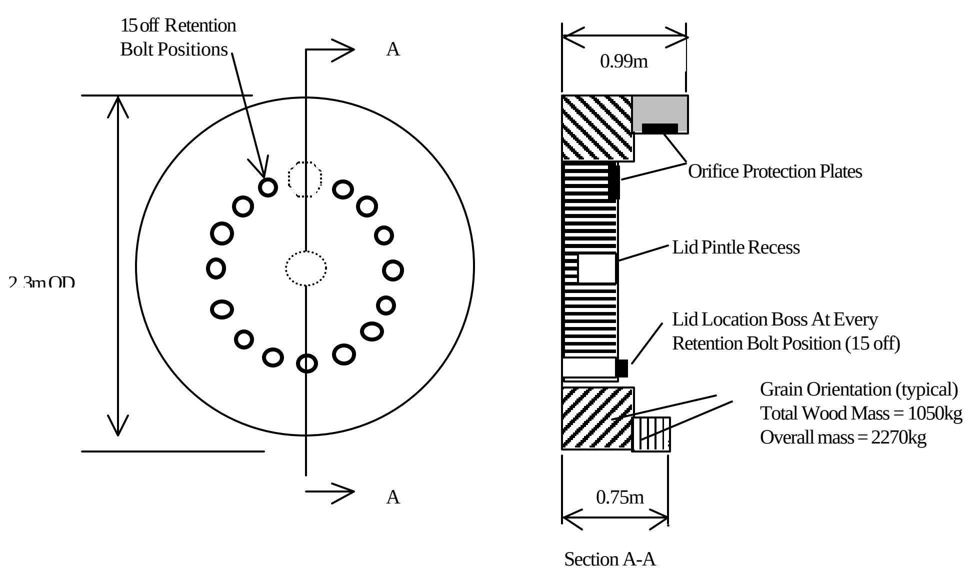


Figure 1 – Schematic of NTL 11 Lid Shock Absorber (not to scale)

Limited to original shock absorber dimensions, BNFL assessed that pinewood was the optimal material to meet their performance objectives, lower density woods not having sufficient energy absorption capacity within the dimensional constraints.

The outer casing of the new NTL 11 shock absorbers is 6mm thick stainless steel, inside which, pinewood blocks are closely packed with grain orientations being designed to ensure optimal energy absorption under all impact orientations. Radial steel webs welded to the inner casing separate sections of the wood blocks to ensure they do not move laterally under severe crushing which could reduce shock-absorbing performance.

The pine itself was selected to be within a density tolerance and dryness to ensure consistency of performance between the drop test model and the full size flask. Close tolerances were applied to the fitting of the pine blocks within the casing to ensure minimal void spaces. The total mass of pinewood in the new NTL 11 shock absorbers is approximately 1050kg (lid) and 600kg (base), the base being of smaller diameter.

The lid shock absorber incorporates a thick steel plate over the vent and ullage orifices to ensure maximum protection to these components from punch damage.

The shock absorbers are located to the flask by bosses at each bolt position, these being designed to ensure a 10mm air gap between the inner casing and the flask, this acting as a thermal barrier under fire conditions.

BACKGROUND TO FIRE TEST

Splits and holes formed in the casing from impact testing result in combustible material being exposed directly to the thermal test fire. Hence, for the revised NTL 11 thermal analysis it was decided to evaluate any potential effects of wood combustion. This was intended to examine implications of the IAEA Regulatory Requirement, (IAEA Safety Series No 6, as amended 1990, para 628) which states;

'*After the cessation of external heat input, the specimen shall not be cooled artificially and any combustion of the specimen shall be allowed to proceed naturally'*

In most thermal performance studies on flasks fitted with wood filled shock absorbers, BNFL considered that the wood is burnt away during the IAEA thermal test and does not act as a heat barrier. BNFL believed this was a pessimistic approach, which they wished to demonstrate by testing.

TEST OBJECTIVES

The specific objective of conducting a thermal test on a NTL 11 shock absorber were as follows; -

a. To determine the thermal protection this design of shock absorber gives to lid features and component parts during the thermal test.

b. To assess the effects of continued burning of the wood material following the cessation of the fire.

To achieve these objectives a full size lid end shock absorber was exposed to a fully engulfing hydrocarbon fire lasting 30 minutes.

DESCRIPTION OF TEST SHOCK ABSORBER

The lid shock absorber for the test was manufactured in accordance with the standard NTL 11 specification except it was 'modified' to represent typical impact damage from a 9m drop followed by a punch test, see Figure 2. This artificially introduced damage did not include crushing of the casing and wood which was not considered relevant for the purpose of the test. Artificial damage was limited to the casing front face and involved exposing the wood over an arc of 120^{o}, this being largely covered by a flap of casing material. Wood exposure was high compared to that resulting from the drop tests but this was not considered detrimental to the test and ensured the wood was visible after the end of the fire. Above this area and offset to the side, a 150mm diameter hole was positioned in the casing, typical of punch damage.

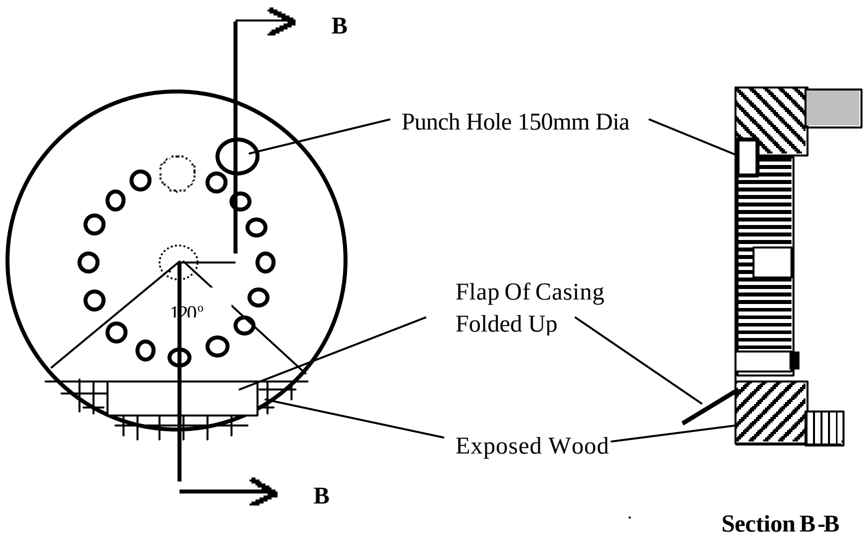


Figure 2 - Schematic Diagram Showing 'Impact Damage' To Casing

TESTING CONFIGARATION

The testing configuration is shown schematically in Figure 3 below

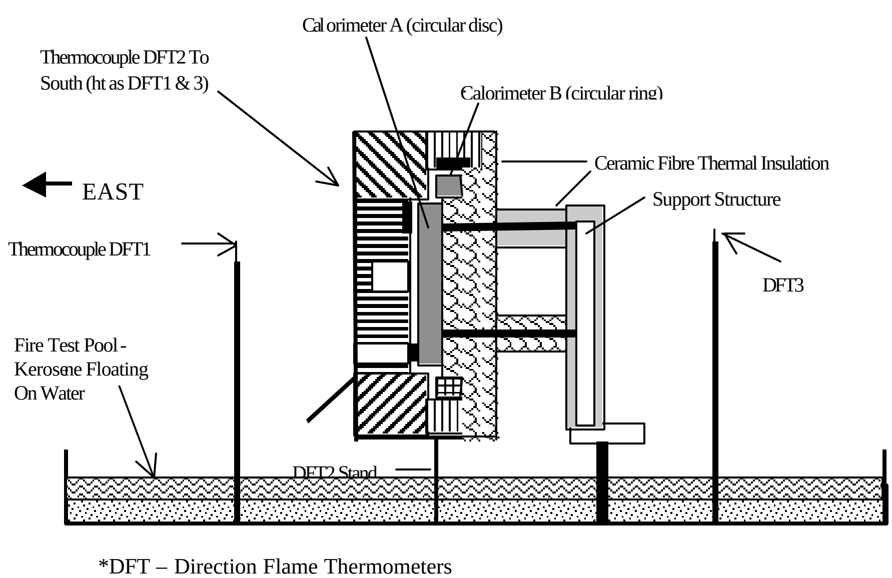


Figure 3 – Schematic Arrangement Of Test Set Up (not to scale)

Analytical studies were first undertaken to assess the arrangement that would best replicate the shock absorber behaviour during and after a thermal accident.

A test arrangement was derived from these studies, based on the shock absorber bolted to masses acting as calorimeters. The objective was to simulate the conditions on the shock absorber surfaces typically experienced during the IAEA thermal test.

The lid shock absorber was bolted, in conventional manner, to a 'dummy' flask lid shown as ***calorimeter A***, weighing 1400kg. This plate was bolted to a thick steel ring shown as ***calorimeter B*** weighing 625kg, which represented the NTL 11 flask lid and body flange bolted connection. Ceramic fibre thermal insulating material, 150mm thick, clad the rear surfaces of the calorimeter plates and all surfaces of the support frame

The assembly was mounted in a fire test pool, which contained fresh water to a depth of 495mm. Floating on top of the water was 8000 litres of kerosene, which had been calculated, would burn for 32 minutes

INSTRUMENTATION

A total of 18 off thermocouples (T) are fitted to the test assembly at the positions shown on Figure 4. A further three were positioned in accordance with IAEA regulatory advisory material for the measurement of flame temperatures, see Figure 3.

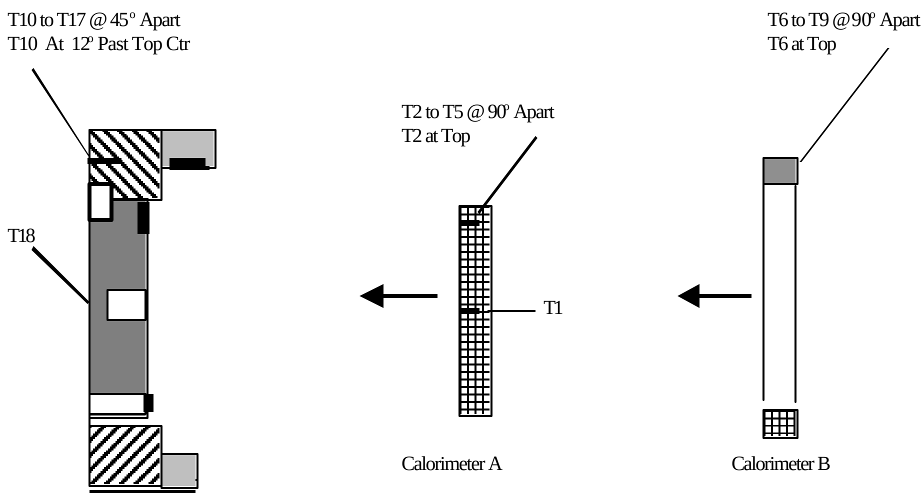


Figure 4 – Position of Thermocouples

Data Logger Outline Specification Below:-

Thermocouple temperature range –120°C to 1370°C
Scan rate 10 channel/sec, 23 channels used
Scan interval 15 sec to 1 hour – output to floppy disk and strip printer
In addition to the thermocouples a wind speed anemometer was positioned 20m from the pool as was a wind vane measuring direction.

Thermocouple ID	Postion	Comments
DFT1 – DFT 3	**DFT1 – East, DFT2 – South DFT3 – West of Test Assembly**	**To measure flame temperatures around test shock absorber**
T1 – T5	***Calorimeter Plate A*** **T1 - Centre Outer Face T2 – T5 Outer Face 90° Apart**	**To assess heat inputs to 'lid' front face**
T6 – T9	***Calorimeter Plate B*** **Outer face 90° Apart**	**To assess radial heat inputs to lid/body flanges**
T10 – T 18	***Test Shock Asorber*** **T10 – T17 In Wood At mid**	**To assess temperature distribution in shock**

	Thickness 45° Apart **T18 - Centre Outer Face**	**absorber casing**

Table 1 – Position And Purpose Of Thermocouples

DESCRIPTION OF TEST

The test took place at the fire test facility on the AEA Winfrith site, Dorset, UK in accordance to BNFL specifications, ref 1.

The average wind speed was less than 2 m/s when the kerosene was ignited at 12.58 hours on Thursday 25th March 1999

Temperatures were logged every 30 secs and the start time was taken from when thermocouples DFT1 to DFT3 were all measuring 800°C.

The fire was then allowed to burn for further 32 minutes by which time the engulfing flames were rapidly dying down as the final kerosene was consumed. At 32 minutes the remaining flames were extinguished using foam directly on to the surface of the water, there was no artificial cooling of the test assembly. The DFTs all had registered temperatures above 800°C for a continuous period of over 30 minutes.

During the test fire the shock absorber was completely engulfed by the fire for the majority of the time, but was briefly visible on occasion as the flame front was deflected by the swirling currents of air generated by the fire.

The site fire brigade and appliance attended the test and were responsible for safety procedures, igniting the fire, its final extinguishing and preventing its spread to other areas. Apart from minor grass fires in the local vicinity the test was completed without incident. After the fire was finally extinguished it was possible to observe the exposed wood in the shock absorber, this was clearly intact although its surface was completely charred with some areas lightly aflame and smoking. The stainless steel casing was partially blackened and rusty patches were evident on the curved sides, slight thermal distortion was evident on the front face plate. The thermal insulation was notably intact and apart from some burn marks on its surface, appeared to have suffered very little during the fire.

The last evidence of burning wood inside the casing was observed on Monday 29th March, four days after the start of the test, the final recording of temperatures was taken 24 hours later.

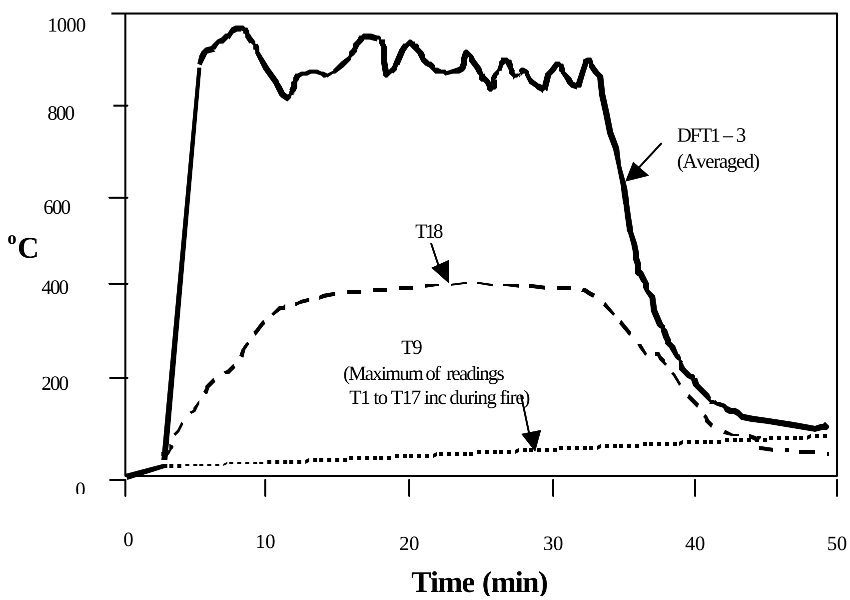
At the end of the four days the wood had virtually completely disappeared , only a few small pieces floating in the pool water and a small amount of charcoal in the casing, estimated to be about 20 litres in volume.

There was no rain during the fire and only light rain for a short period over the following four days.

TEST RESULTS

Results of thermocouple readings and other data were presented in the AEAT test report, Ref 2.

A substantial amount of data was generated by the test, only a summary of which can be presented in this paper.

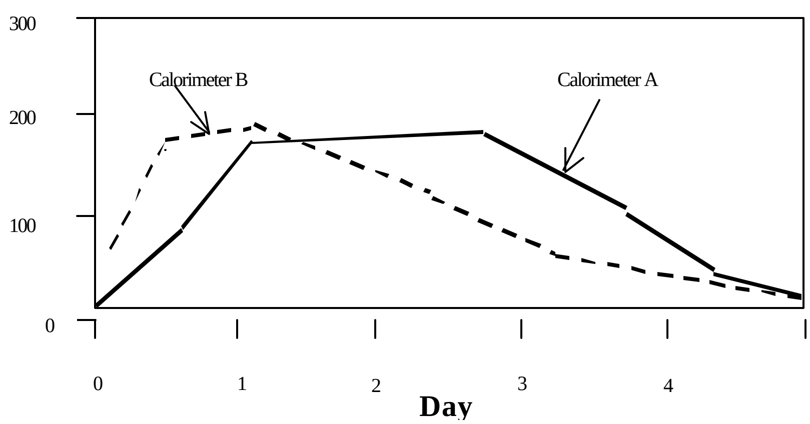


Graph 1 - Temperatures in System Up To 50 Minutes From Start

Graph 1 gives a summary of the temperature readings from all thermocouples both during and soon after the fire event, all thermocouple readings were 9°C at the start of the test. All 3 readings of flame temperatures showed a consistent pattern including frequent fluctuations, sometimes as high as 200°C, this was probably due to temperature variations within the local flame profile.

The single thermocouple on shock absorber casing, T18, showed the only other significant reading during the fire, reaching approximately 400°C within 10 minutes, at which it remained, until the end of the fire.This temperature reading fell rapidly afterwards and 100 minutes later had fallen to about 40°C, never to rise again.

Other temperatures readings, T1 to T17 inclusive, showed much smaller increases during the fire.



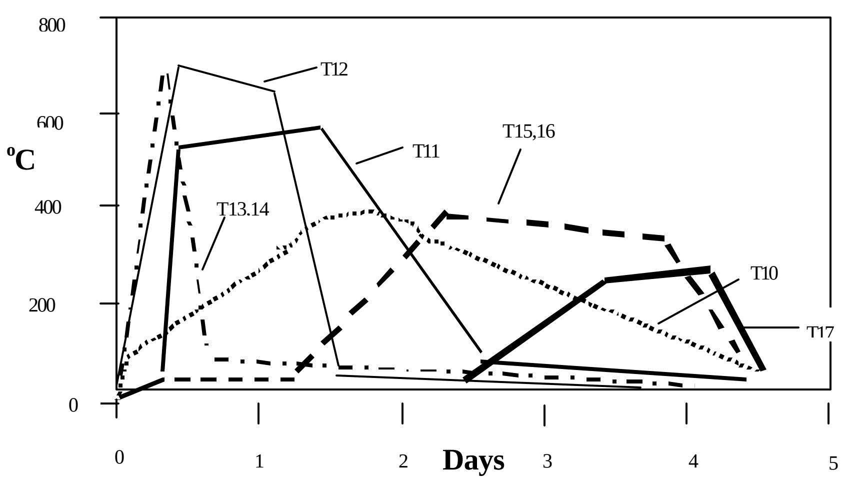
Graph 2 – Calorimeter Plate Temperatures (Maximums)

Graph 2 above shows the maximum temperatures on the calorimeters throughout the test. At the end of the fire the temperatures on calorimeter A showed negligible increase, the highest being 2°C rise after 35 minutes. However T9, on calorimeter B, recorded an increase of 85°C whilst the increase in T6 to T8 was approximately 7°C. T9 continued to slowly rise for a further 20 minutes before falling and by 300 minutes in to the test T6 to T9 inclusive were showing a total increase of approximately 55°C.

Some variations in temperature were evident on each calorimeter at different periods through the test. For instance, approximately 0.5 days in to the test, T8 had risen to 170°C before falling, T9 later showing the maximum temperature on calorimeter B of 190°C, just after 1 day in to the test, by which time T8 had dropped to 130°C.

The temperatures on calorimeter A showed similar variations but on average took longer to heat up and remained near to its maximum for a greater period of time.

Graph 3 indicates the temperatures measured in the shock absorber casing. As may be anticipated, the maximum temperatures are measured adjacent to where the wood was burning while other areas were relatively cool. The results clearly indicate that the wood first burns near to where it is exposed to the fire and spreads to other regions as it is consumed. Later, the temperatures readings become more random as some wood blocks fall down as the wood beneath burns away. After about 2 days the majority of burning wood seems to be located in the lower part on the opposite side to the punch hole, although the heat rising is generating temperatures of over 400°C in the upper regions of the casing.



Graph 3 – Temperatures in Shock Absorber (Linearised)

DISCUSSION

The fire test on the shock absorber had demonstrated it provided nearly total thermal protection to the lid during the IAEA fire. This confirmed that assumptions applied to the thermal analysis were pessimistic, as these took no credit for the thermal protection given by the wood during the fire.

The continued burning of the wood for several days after the 30 minute fire was less expected and found to introduce heating in to the lid during this period. Pessimistic analysis of the data indicates that 1.5kW continuously enters the flat face of the lid from 6 to 72 hours after the start of the fire. Likewise 2.0kW enters the lid/body flange area from 1 to 24 hours after the start of the fire.

Introducing these heat inputs in to the thermal analysis showed no increases in the temperatures of lid components. In fact, the overall effect of the heat barrier caused by the wood during the fire more than offset any adverse effects of the subsequent wood burning. However in the final thermal analysis of the NTL 11 flask, only the effects of wood burning were considered, insulation during the fire event was ignored. This did not result in higher seal temperatures, the only effect being a very slight extension of the post fire cooling period.

CONCLUSION

The fire test on the NTL 11 shock absorber confirmed assumptions in the theoretical analysis of fire conditions gave pessimistically high temperatures in the lid area.

Continued burning of the wood after the fire had a virtually insignificant effect on the NTL 11 flask temperatures, but all future analysis by BNFL of fire accident conditions on flasks would take this in to account.

REFERENCES

1. TD/ETS/S/99/29 – Specification For Fire Test on NTL 11 Full-Size Shock Absorber.

2. AEAT – 5718 - Fire Testing of NTL 11 Lid Shock Absorber – J Gillard – June 99.