

001-001/2003

Unique No: HPB 32114N

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ACTION 1 NSD		DATE
ACTION	LETTER	DOCUMENT
[REDACTED]	✓	✓
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7th June 2006

Hinkley Point B Power Station  
EC317558: Safety Case for Heat Shield Gimbal Joints

Further to the Level 4 meeting held at Barnwood on 22<sup>nd</sup> March, please note the current status of those Actions placed at that meeting that relate directly to the above EC. The EC is currently undergoing its Independent Nuclear Safety Assessment:-

**Action 1.** To assess whether safety case issues arising from the Lifetime Materials Project have been adequately addressed in PSR2, and to consider whether more urgent action might be needed in the event of adverse findings. [REDACTED]

**Status :** Not relevant to EC 317558

**Action 2.** To see whether the Esshete 1250 data support the relationship suggested for the 300-series austenitics wrt the relative changes of fracture toughness at room temperature and at elevated temperature. [REDACTED]

**Status:** Not relevant to EC 317558

**Action 3.** Confirm that the crack growth in the AISI 321 tube HAZ is bounded by that in the 347 weld, when both are in the aged condition. [REDACTED]

**Status:** A memorandum has been sent from [REDACTED] to [REDACTED] (copy attached) explaining the why it is judged that a creep-fatigue crack will grow more slowly in the HAZ of the 321 parent than in the adjacent 347 weld. This memorandum forms ref.32 to the EC. The EC also includes a commitment to carry out an independent verification of finite element model previously used to calculate the AISI 321 crack growth rate. The complexity of the analysis is such that several months will be needed verify or repeat the analysis carried out c. 2002 but not formally verified.

A copy of ref.32, 'Hinkley Point B/Hunterston B: Consideration of Creep-Fatigue Crack Growth in the Fuel Plug Unit Heat Shield Gimbal Joint Lower Half Under Low Power Refuelling Conditions, memo from [REDACTED] Assessment Technology Group, to [REDACTED] Fuel Route Systems Branch, ref. E/TSK/HPH/3463/DWD1, FRSB Taskfile HPB/30813, 8<sup>th</sup> May 2006' is attached.

**Action 4.** To consider the benefits of future speculative inspection once the 100% inspection of 'Weld Bs' is complete. [REDACTED]

**Status:** The EC commits to a continuing sample inspection of Weld B's during 'full' plug unit maintenance, which is carried out on approximately 4 plug units per year. In addition the EC commits to a review of the practicability of inspecting other plug unit welds as part of the long-term case.

**Action 5.** To consider whether weld metallographic replications of Weld B should form a specific commitment of EC 317558. [REDACTED]

**Status:** Replicas of two Weld B's with normal eddy current responses have recently been obtained and the initial findings are that they do not exhibit the large grain size in the HAZ that had been a feature of the welds with an 'anomalous' eddy current response. A different etch preparation will be needed for future replicas to obtain finer detail of the grain structure. The issue of anomalous eddy current response is a generic one and is being pursued under the Lifetime Materials Project. It was therefore concluded that no specific commitment was needed in the EC.

**Action 6.** To include a table in EC 3175558 listing the plug unit materials and material properties used in the assessments. [REDACTED]

**Status:** An attempt to assemble all the material data used in the gimbal joints assessments did not prove helpful because of the different combinations of upper bound, lower bound and mean properties that have been used, justifiably, in different assessments and sensitivity studies. The situation is made more complicated by the constitutive laws used in the main assessments. I have confirmed that adequate materials data have been provided in the recent assessments. These assessments include the calculation of critical defect depths (refs.19 and 25 to the EC) and the review of crack growth rates (ref.32).

The relevant references from the EC are shown below. The first two were, I believe, passed to you at our meeting. Ref. 32 is attached.

19. Hinkley Point B/Hunterston B: Effects of Thermal Ageing on the Integrity of the Fuel Plug Unit Heat Shield Gimbal Joint Lower Half under Low Power Refuelling Operations, E/EAN/BDBB/0021/AGR/05, Rev 001, [REDACTED] 30<sup>th</sup> January 2006

25. Hinkley Point B / Hunterston B Power Stations; Revised Limiting Defect Size Calculations For Heat Shield Gimbal Joint Lower Half to Account for the Latest Materials Property Advice and Fault Loading, E/EAN/BDGGB/0128/AGR/06 Rev 000, [REDACTED] March 2006

**Action 7.** To establish whether or how the inspection results in E/EAN/HPB/0104/00 have been formally included in the Reheat Cracking Safety Case and, given that NP/SC 4274 gave a commitment to inspect, whether the BE process has been followed to modify the Cat 1 safety case. [REDACTED]

**Status:** The issue of reheat cracking will be explicitly addressed in the EC, from which the following text is taken:

'The plug units welds were at one time also considered to be at risk from reheat cracking, particularly if they had been repaired (ref.6). Sample in-service inspections were undertaken of the welds considered to be at greatest risk but no evidence of cracking was found. In 1997 a Category One submission, NP/SC 4274 (ref.20) concluded that the frequency of reheat cracking in plug unit welds did not threaten the safety case assumptions for a dropped part-assembly; a commitment was nevertheless made to report the results of further inspections of repaired welds to the Health Safety and Environment Division (HSED). It was reported in ref.21 that no cracks had been discovered and the inspection of plug unit welds for re-heat cracking damage ceased in 2000.'

The relevant references from the EC are:

6. Hinkley Point B: A Review of the Integrity of Fuel Plug Unit Welds, EPD/HPB/EAN/0302/98, [REDACTED] January 1999
20. Hinkley Point B Power Station Nuclear Safety Committee. A Consolidated Reheat Cracking Safety Case Covering all Stainless Steel Welds Internal and External to the Reactor, [REDACTED] NP/SC 4274, May 1997.
21. A Review of the Inspection Results from Repaired Hinkley Point B Plug Unit Welds, E/EAN/HPB/0104/00, [REDACTED] 19<sup>th</sup> December 2000

From discussions with the Author of ref.6 it has been established that he was unaware that NP/SC 4274 had concluded a year earlier that the plug units were not at significant risk from reheat cracking. This is supported

by the fact that ref.6 attributes the concern over reheat cracking to an earlier (1996) report that was superseded by ref.20.

I trust that these responses are satisfactory. Please do not hesitate to contact me if you need any further information.

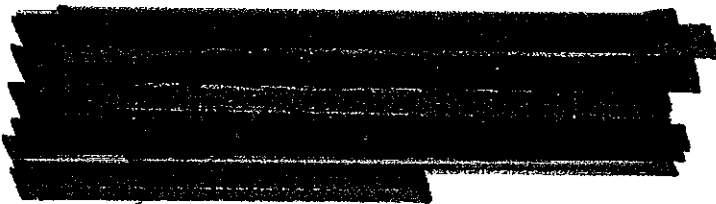
Yours sincerely:-



Fuel Route Systems Branch  
Barnwood



cc



To: [REDACTED]

From: [REDACTED]

Ref: E/TSK/HPH/3463/DWD1

Date: 8th May 2006

**Hinkley Point B/Hunterston B: Consideration of Creep-Fatigue Crack Growth in the Fuel Plug Unit Heat Shield Gimbal Joint Lower Half Under Low Power Refuelling Conditions**

The assessment of creep-fatigue crack growth in the heat shield gimbal joint lower half under low power refuelling conditions [1] evaluated an upper bound estimate of the creep-fatigue crack growth in Type 347 weld metal of 0.084 mm/cycle. This assessment concluded that it was possible to justify [REDACTED] allowable refuelling cycles by estimating the number of cycles to grow an initial crack 1mm deep to a depth of 2mm based on this upper bound estimate of the creep-fatigue crack growth. Critical defect sizes for both the Type 321 tube and Type 347 weld materials were calculated to be in excess of 2mm for a "hangman's drop" fault occurring during the discharge transient and assuming material properties for a temperature of 500°C [1]. However, these calculations did not allow for the effects of thermal ageing on fracture toughness. Consideration of the effects of thermal ageing on fracture toughness has resulted in a reduction in the critical defect size (to 1.67mm) and a new reduced limit of [REDACTED] allowable refuelling cycles [2] using the upper bound creep-fatigue crack growth estimate of 0.084 mm/cycle [1].

The upper bound creep-fatigue crack growth estimate of 0.084 mm/cycle was derived in [1] for a crack located at the centre of the weld on the outer surface and assuming that the weld cap was essentially flush with the adjacent tube and casting. This value took account of significant conservatism (greater than an order of magnitude) in the calculated mean creep crack growth rates in Type 347 weld metal compared with the creep crack growth rates observed in the full-scale rig test; for this reason calculated mean and upper bound creep crack growth rates for reactor low power refuelling conditions were reduced by a factor of 10 [1]. The sensitivity of creep-fatigue crack growth rates to the crack location within the weld and the weld cap profile was considered in Section 12.5 of Reference 1. This concluded that the creep-fatigue crack growth estimate of 0.084 mm/cycle remained bounding for a crack in the weld metal close to the tube fusion boundary even when a local stress concentration feature was introduced in the form of a distinct weld cap [3]. Subsequently, additional calculations were carried out to estimate creep-fatigue growth rates for a crack in the heat affected zone (HAZ) of the Type 321 tube [4]. These latter calculations were carried out using a model incorporating a distinct weld cap and they resulted in an upper bound estimate of the creep-fatigue crack growth in Type 321 HAZ of 0.035 mm/cycle. Creep and fatigue contributions to the upper bound creep-fatigue crack growth rates for Type 347 weld metal and Type 321 HAZ are summarised in the following table.

Crack Growth	Upper bound crack growth per cycle of refuelling (mm)	
	Type 347 Weld Metal [1]	Type 321 HAZ [4]
Fatigue	0.047	0.017
Creep	0.037	0.018
Creep-Fatigue (Total)	0.084	0.035

It is useful to compare the upper bound fatigue and creep crack growth equations which have been used to estimate the above crack growth rates. Fatigue crack growth rates (m/cycle) have been estimated using

$$da/dN = C\Delta K_{eff}^{\ell}$$

where  $\Delta K_{eff}$  is the effective stress intensity factor range ( $MPa\sqrt{m}$ ) and  $C$  and  $\ell$  are constants. Creep crack growth rates (m/h) have been estimated using

$$da/dt = A(C^*)^q$$

where  $C^*$  is in  $MPa.m/h$  and  $A$  and  $q$  are constants. The constants used to determine upper bound crack growth rates for Type 347 weld metal [1] and Type 321 HAZ [4] are summarised below

Crack Growth	Constant	Values to give upper bound crack growth rates	
		Type 347 Weld Metal [1, 5]	Type 321 HAZ [4, 6]
Fatigue (m/cycle)	$C$	$9.52 \times 10^{-12}$	$2.0 \times 10^{-13}$
	$\ell$	3.8	4.7
Creep (m/h)	$A$	$0.5 (0.05)^1$	0.02
	$q$	0.91	0.9

For relevant values of  $\Delta K_{eff}$  and  $C^*$ , fatigue and effective<sup>1</sup> creep crack growth rates in Type 347 weld metal are approximately twice those in Type 321 HAZ. If it is assumed that the loading conditions in the HAZ are similar to those in the weld metal, an approximate estimate of creep-fatigue crack growth rates in the Type 321 HAZ can be obtained by halving the value for Type 347 weld metal (0.084 mm/cycle). This results in an estimated creep-fatigue crack growth rate in the Type 321 HAZ of 0.042 mm/cycle, which is close to, but slightly higher than, the value of 0.035 mm/cycle calculated in Reference 4. Alternatively, it is useful to consider the increase in loading level which would be required to give creep-fatigue crack growth rates in the Type 321 HAZ, which are as high as those calculated for Type 347 weld metal (i.e. 0.084 mm/cycle) [1]. Approximate calculations indicate that this would require the load levels in the HAZ to be approximately 20% higher than those in the weld metal, and as this is considered to be very unlikely, it is judged that in practice creep-fatigue crack growth rates in the Type 321 HAZ will be bounded by the value of 0.084 mm/cycle calculated for Type 347 weld metal.

In addition, it is judged that the upper bound ligament creep damage of 0.016 per refuelling cycle calculated for Type 347 weld metal [1] will also be bounding for the Type 321 HAZ and tube materials on the basis that the potentially higher elastic follow-up factors and creep strains in the Type 321 tube will be more than outweighed by the higher ductility of the Type 321 HAZ and tube materials (lower bound value of 5.9%) compared with the Type 347 weld metal (lower bound lower shelf value of 0.76%). This judgement is qualitatively supported by the lower values of creep damage calculated for the Type 321 HAZ and tube materials compared with the Type 347 weld metal in the uncracked structure [7].

In summary, it is judged that that the upper bound values of creep-fatigue crack growth (0.084 mm/cycle) and ligament creep damage (0.016/cycle) calculated for a crack in the Type 347 weld metal are bounding for a crack located in the HAZ of the Type 321 tube.

## References

1. [REDACTED] Hinkley Point B and Hunterston B Power Stations: Creep-Fatigue Crack Growth Assessment of the Heat Shield Gimbal Joint Lower Half Under Low-Power Refuelling Operations, E/REP/STAN/0091/AGR/01 Revision 000 (2001).
2. [REDACTED] Hinkley Point B/Hunterston B: Effects of Thermal Ageing on the Integrity of the Fuel Plug Unit Heat Shield Gimbal Joint Lower Half Under Low-Power Refuelling Operations, E/EAN/BDBB/0021/AGR/05 Revision 001 (2006).

<sup>1</sup> Noting that calculated creep crack growth rates For Type 347 weld metal based on  $A = 0.5$  were reduced by a factor of 10 based on observations from the full-scale rig test [1]. This is equivalent to assuming  $A = 0.05$ . Creep crack growth rates for Type 321 HAZ have not been factored.

3. [REDACTED] Details of the FE Calculations Carried Out for a Crack Located Close to the Weld/Tube Fusion Boundary, Task File SAG 40227 Item 14 (2001).
4. [REDACTED] Details of the FE Calculations Carried Out for a Crack Located in the Tube HAZ, Task File SAG 40227 Item 28 (2002).
5. [REDACTED] The Creep, Fatigue and Creep-Fatigue Crack Growth Behaviour of an Austenitic Type 347 Weld Metal at 650°C, E/REP/ATEC/0018/AGR/01 Revision 000 (2001).
6. [REDACTED] AGR Materials Data Handbook, R66, Issue 6 (2003).
7. [REDACTED] Hinkley Point B and Hunterston B Power Stations: Creep-Fatigue Crack Initiation Assessment of the Heat Shield Gimbal Joint Lower Half Under Low-Power Refuelling Operations, E/REP/STAN/0119/AGR/01 Revision 000 (2002).

cc:

[REDACTED]