Tutorial Session 29 (T73S06) – Inspection Requirements due to Creep

Last update: 7/1/15

Inspection requirements following from creep rupture assessments: TGN(CTS) requirements and assessment assumptions (data bounds): TGN043,044,046; Additional requirements for HI, IOGF, IOF items; Relaxed rules for "frequent" items; Procedure if lower bound life expires (CMV); Performance of structural assessment cf metallurgical examination; Type IV damage, cavity counting v life fraction.

WARNING: The very brief summary of the Inspection Guidelines' requirements herein does not include *all* their requirements. Attention is largely restricted to creep issues. There is no substitute for reading the Guidelines themselves.

Qu.: What are the "Inspection Guidelines"?

The "Inspection Guidelines" are a suite of documents, mostly in the form of "Technical Guidance Notes" (TGNs) – see the References. However there are also some higher level documents, "Company Technical Standards" (CTSs) which can contain inspection requirements (e.g. Refs.[19,24,25]).

There used to be an older suite of documents, "British Energy Operations Memoranda" (BEOMs) which have gradually been updated and replaced by CTSs.

Qu.: Are the "Inspection Guidelines" Mandatory?

The CTSs are clear in specifying what is mandatory advice (most of it!). I am not sure of the formal position regarding the TGNs (the word "guidance" blurs the issue). However, in practice the TGNs are effectively mandatory because a great many Category 1 and 2 safety cases make reference to the inspection guidelines / TGNs as defining the required inspection strategy.

Qu.: Which Inspection Guidelines are relevant in this session?

Generally, only the guidelines which contain inspection requirements driven by creep issues will be covered here.

Qu.: Which Guidelines will we ***not*** cover?

In addition to those TGNs/CTSs without any creep issues, we shall mention only in passing those for, (a)pipework hangers; (b)CLA; (c)high temperature threaded fasteners.

Pipework Hangers (TGN081, Ref.[20]): The hangers themselves will not be creeping (we hope!) and so the inspection (survey) requirements are not creep related. However, hanger positional surveys are indirectly related to creep of the pipework, potentially at least.

Component Life Assessment (CLA), CTS209, Ref.[24]: This concerns items within the primary pressure boundary only and does not directly address inspection requirements. However, CLA is certainly all about creep. Moreover, problematical components might require action to be taken beyond the routine CLA assessments. In principle this may be inspection, though for items within the PCPV this is rare due to the difficulty of such inspections (other than video).

High Temperature Threaded Fasteners (CTS102, Ref.[25]): This document does not cover fasteners operating above 575^{o}C or items within the reactor pressure vessel. (I presume these default to being addressed by CLA, and hence CTS209). This CTS advises specific maximum fastener lives against temperature for the range of materials used. For many (most?) such fasteners, replacement can be expected within the station's operating life. A unique issue for such fasteners is that creep strains far less than those which will fail the stud are nevertheless a threat to the plant because relaxation of the stud tightening load can lead to joint leakage. Hence CTS102 also advises maximum times between re-tightening of the studs/nuts. Note that the more frequent the re-tightening, the shorter will be the stud life. Hence there is an optimal balance between leak avoidance and stud failure avoidance.

Qu.: Corrosion and Flow Accelerated Corrosion

One of the most important areas which will not be addressed in detail here, due to being a low temperature issue, is corrosion. Corrosion is one of, probably the most, significant degradation mechanism in our plant. The issue of inspection of sea water systems, which are the most prone to corrosion, is addressed by TGN 88 (Ref.22).

The other common, and serious, corrosion mechanism occurs in pipework systems containing fast flowing water. Susceptible systems are those composed of material with no Cr, essentially carbon or CMn steels, and hence low temperature systems. Such systems may experience a virulent mechanism in which erosion and corrosion act synergistically, referred to as "FAC" (flow accelerated corrosion).

The inspection requirements associated with FAC, addressed by TGN 92, are particularly onerous because they tend to involved 'mapping' thicknesses over an area of pipework (as contrasted with, say, four cardinal point measurements of a weld). Assessment of FAC inspections can also be more onerous because the rate of thickness loss involves consideration of previous inspection results. FAC inspections have become amongst the most burdensome of pipework inspections in recent years. This is, however, commensurate with their threat.

TGN92 is one of the most recent TGNs. Until relatively recently there was no specific requirement to inspection for FAC. This was a serious shortcoming in our procedures. The accident at Mihama in Japan, Ref.[30], was the impetus for getting our house in order on FAC.

Qu.: So which inspection guidelines does this leave?

This leaves only TGNs 43, 44 and 46 to be discussed here. These relate to CMV pipework, austenitic pipework and headers, and transition joints. These are considered in turn below.

Qu.: Do the Inspection Guidelines address all IOF/IOGF/HI requirements?

No. The inspection guidelines are intended to be sufficient only to justify a claim of infrequent failure. Remember that there are also higher nuclear safety duty classes,

IOF = Incredibility of Failure

IOGF = Incredibility of Guillotine Failure

HI = High Integrity

Qu.: So where are the inspection requirements for IOF/IOGF/HI items defined?

The inspection requirements for these higher nuclear safety duty categories are far more stringent than for "frequent/infrequent" items. The actual requirements are agreed on a case-by-case basis, depending upon the structure of the safety case. However general guidance on the ingredients required in such safety cases is given in BEG/SPEC/DAO/011, Ref.[26]. In particular the recommended inspection strategy is summarised in Table 2 of Ref.[26], reproduced below. (Note that this is a <u>draft</u> of revision 2 at the time of writing).

Generally all IOF/IOGF/HI welds/features require inspection on some rolling programme, generally at least 25% of a given population of welds at each statutory outage (100% inspection every 12 years).

Items with a particular integrity threat may require a greater sample inspected at each outage, possibly 100%.

So-called safe-lives play a major role in the inspection requirements for IOF/IOGF/HI items. These provide a protection against failure based on structural assessment assuming defects at the NDT tolerance size escape detection at the last inspection and subsequently grow at the upper bound rate predicted using R5V4/5. The intention is that the safe life covers the period between inspections. This may require earlier inspections than the standard 12 year rolling programme.

The term "safe-life" assessment is rather unfortunate since it could apply to virtually any assessment. However the term has come to mean specifically the type of assessment described above, i.e., postulating a defect at the NDT tolerance size, even though the inspection may be clear, and then assessing upper bound growth (R5V4/5) to a final size based on an R6 critical crack size calculation. The full procedure is given in IMAN#5 which can be found in G:\Engineering\SISB\Ltasks\SAG\Standards\IMANs (but may not be referenced!).

A key part of the Safe Life procedure is the "95% Rule" which sets the crack growth initiation time at 95% of the inspection time. This is important because R5V4/5 creep crack growth rates are usually much faster initially than later on (due to the transient spike in C(t) versus time). We'll address safe lives in more detail in session 44.

Note, however, that IMAN#5 does not apply to reheat cracks. Both crack depth and initiation time will differ for reheat cracks compared with the assumptions in the true "safe life" methodology of IMAN#5. BEG/SPEC/DAO/011, Ref.[26], is rather misleading in using the same term, "safe life", in the context of reheat cracks.

The rest of this session is concerned with requirements for F/IF plant.

Qu.: What defines "Infrequent" and "Frequent" Items?

Note that "Infrequent" (IF) and "Frequent" (F) are just short-hand for "items whose failure is deemed tolerable on a frequent (or infrequent) basis".

The terms "frequent" and "infrequent" have a recognised meaning in nuclear safety case speak, which differs from their colloquial usage. "Frequent" failure means a probability of failure $\geq 10^{-3}$ per reactor year, i.e., a failure every 1000 reactor years, which is hardly frequent in the conventional sense. "Infrequent" failure means a failure probability $<10^{-3}$ per reactor year.

When are items classes as IF or F? An item is "infrequent" if there is one independent line of protection. This means that, if the IF item were to fail, there is an independent system which will permit the reactor to be safely shutdown, held down and post-trip cooled. A "frequent" item requires two separate, independent lines of defence.

Qu.: What defines IOF, IOGF and HI Items?

IOF items have no line of defence should they fail. Hence the requirement for thier failure to be deemed incredible.

IOGF pipes also have no line of defence should they fail by guillotine failure, i.e., complete break. Often this is because the resulting pipe whip has been assessed to have an intolerable consequence, e.g., knocking out some adjacent essential equipment. But it may be possible to demonstrate acceptable leakage from an IOGF pipe, and hence the assessment criteria for IOGF may be relaxed compared to those for IOF.

The High Integrity (HI) category applies when a partial claim can be made on a line of defence, but for which the claim is not sufficiently robust to permit down-rating to "Infrequent". In practice, IOGF and HI are required to meet similar assessment standards, intermediate between IOF and IF.

RECOMMENDED INSPECTION LEVELS FOR IOF, IOGF AND HI WELDS, WHERE REASONABLY PRACTICABLE) - EXTRACT FROM DRAFT REF.26 (TABLE 2)

Mechanism	Assessment Parameter	Inspection Sample Size
Creep, Fatigue and Creep-Fatigue Crack Growth	Conservative predictions of creep and fatigue crack growth of a postulated *defect* that bounds the size that could have been missed by inspection or of a known *defect* if present (accounting for sizing errors). Safe life is defined as the time for the above *defect* to grow to the limiting size at which failure is predicted.	• Welds shall be inspected every 12 years or at a period of less than the predicted safe life, whichever is the lesser. The number of welds inspected should ideally be roughly equal at each statutory outage over the inspection cycle. • Parent material where the predicted damage exceeds 50% shall be subject to inspection at the next statutory outage. The re-inspection interval shall not be greater than 12 years. The assessed damage fraction shall not be allowed to reach unity (100%) without further inspection.
Reheat Cracking Risk classification in accordance with Ref. 6.14 (High, At Risk and Low).	Conservative safe life predictions accounting for the time for the defect to form and start to grow by conventional creep- fatigue crack growth. The safe life predictions shall conform to the requirements defined in the safety case.	• The inspections shall conform to the requirements defined in the safety case and TGN 044 - Guidelines for the Inspection of Austenitic Stainless Steel Steam Pipework and Headers on AGR Plant. The inspections requirements are dependent upon the risk classification. • Any weld shall be inspected every 12 years or at a period of less than the predicted safe life, whichever is the lesser. The number of welds inspected should ideally be roughly equal at each statutory outage over the inspection cycle. • Parent material is not susceptible to reheat cracking so no inspections are required.
Environmentally Assisted Cracking (EAC)	Crack growth accounting for combined EAC and creep, fatigue and creep-fatigue shall be considered.	• The inspections shall conform to the requirements defined in the safety case and relevant TGNs.
Flow Accelerated Corrosion (FAC)	Thickness assessment.	• FAC inspections are controlled by the requirements of TGN 92.
General	For all welds and parent material where cracking is predicted to be present by any mechanism, inspections at the next available opportunity shall be considered. The implications to the safety case shall be addressed and use made of the safety case anomalies procedure (Ref 6.22).	

TGN043 (CMV)

Qu.: What is the purpose of the inspection guidelines of TGN043?

...to ensure failure is infrequent.

Qu.: What are the creep-based inspection requirements for IF CMV welds?

There is no substitute for reading the TGN itself. However, in brief TGN043 requires,

- An inventory of CMV welds must be maintained. This is fulfilled by the WID (Weld Inventory Database);
- The *lower bound* creep rupture life for all welds (assumed undefective) within the CMV inventory must be calculated using R5V7. This must cover all weldment zones;
- The TGN does not define what is meant by "lower bound" in this context. The usual practice is to define this as the use of lower bound creep rupture data, though other data (temperatures, stresses) may be closer to best estimates.
- Items must be inspected if their lower bound creep life usage at the outage *following* the outage in question is predicted to exceed 80%. As well as welds, this applies to certain potentially vulnerable parent features, e.g., bends;
- Items selected for inspection on this basis (the 80% rule) must also be replicated, as well as subject to the usual NDT. The purpose of the replica is to carry out cavity density counting in the HAZ, thus providing a metallurgically based estimate of creep life usage;

The TGN is not prescriptive regarding how frequently the creep life estimates are updated. Custom and practice has, in the past, been to update creep lives prior to each statutory outage. However, in recent years it has been recognised that it may be a waste of effort to continually re-assess the lives of welds when there has been little to change the result. Hence, re-assessment of creep lives is required only if something significant has changed, e.g., significant thinning of the item due to preparation for inspection, or a change to the assessment procedure or material property recommendations. Otherwise, the creep life calculated for a previous outage may be retained.

The MECT (mean effective creep temperature) which is assumed, both for the historic operation and the future operation, can affect the predicted remnant life very sensitively. For this reason, creep life updates are generally preceded by an update of the MECTs.

Items in the "frequent" tolerability of failure category may be subject to less onerous criteria (see below).

Qu.: What are the non-creep based inspection requirements in TGN043?

The broad categories of the non-creep requirements are,

- Thermal fatigue cracking (of which TTIBC is one type);
- Speculative inspections.

The areas potentially at risk of thermal fatigue cracking are described in TGN043.

Speculative inspections are important as a complement to the risk-based inspections. The purpose is to identify the unexpected.

- TGN043 defines a number of categories of CMV weldment of differing level of risk. The highest risk category are section changes at steam chests, valves, strainers, etc., together with large bore branches and trunnions;
- For about half of the categories, 5% of the population must be selected for inspection at each statutory outage. For the other half of the categories, the required sample is 2%;
- These speculative samples are in addition to items selected for other reasons (i.e., due to being IOF/IOGF/HI or due to the 80% rupture life rule);
- The ideal is that the speculative sample will involve different items at each successive outage, thus maximising the number of components inspected at some time during service.

Qu.: What exactly does "inspection" mean in TGN043 (CMV)?

The guidance regarding what NDT techniques are to be deployed, and their broad-brush capability, is given in Section 4.8 of TGN043,

> "*Wherever possible, CMV components should be subject to full surface and volumetric inspection. However, it is acknowledged that the geometry of certain smaller components may be such that it is only practicable to undertake surface inspection. Alternatively, for some components targeted for specific degradation issues, the inspection area may be limited accordingly (e.g. thermal fatigue cracking at the internal branch corner of small bore attachments; creep cracking at the extrados of bends).*
>
> *The principal NDT techniques to be used are magnetic particle inspection (MPI) and ultrasonics, with dye penetrant inspection (DPI) and radiography available as alternatives if necessitated by the component size, geometry or accessibility. In practice, the precise NDT procedures and techniques to be utilised for any given component shall be confirmed by Inspection Group personnel.*"

Qu.: "Full Volumetric Inspection" - Really?

I have a misgiving about the claim that "full volumetric inspection" is carried out. My understanding is that the bore region (e.g., the root area of butt welds) is not covered by the standard ultrasonic procedures for the thicker pipes. This means that inspections for, say, TTIBC (thermal transient induced bore cracking) need to request specific types of inspection. The normal procedures can miss such defects.

Qu.: What is the current position on TTIBC inspections?

Ref.[1] Section 4.6.2 states,

A detailed crack initiation and growth analysis was undertaken for the bounding AGR location in 2001, which concluded that this damage mechanism was not expected to pose a threat to AGR weld integrity over the remaining station lifetimes (Ref.32). *Furthermore, the majority of welds with the highest potential susceptibility were subjected to inspection using targeted ultrasonic techniques during outages between 2001 and 2006 with no cases of TTIBC being identified. Consequently, no specific inspections are required for this degradation mechanism on AGR plant, noting that the conventional ultrasonic techniques deployed under speculative inspection programmes will continue to provide a measure of forewarning should significant TTIBC defects occur in future.*

Qu.: Thickness Measurements

Also, all items subject to ultrasonic inspection (i.e., most things) will have their thicknesses measured and recorded. The measured thickness is currently checked against a required thickness entered in the OMD (Outage Management Database) and referred to SAG if under-thick.

Qu.: Replication / Cavity Counting

Other things which *may* also be required include,

- Replication and cavity counting for items with high assessed creep life usage (e.g., items selected under the 80% rule) and possibly items with defects;
- Chemical composition checks – for classes of item where this has not been confirmed by other means.

Qu.: What happens if the lower bound creep rupture life is >80%

Items in the F/IF category are not automatically deemed unacceptable simply because the R5V7 lower bound rupture life exceeds 80% (or even 100%). However, due to the 80% rule, such items would be flagged for re-inspection at every outage. This might be undesirable due to the successive thinning which preparation for inspection requires. The procedure in such cases would typically be,

- Replication and cavity counting: Cavities in the Type IV region can be correlated with damage (see Ref.[27] and Figure 1 below);
- If the above metallurgical assessment of damage is consistent with the damage calculated on the basis of best estimate rupture data, then switch to using best estimate rupture data for this particular item;
- A re-inspection strategy is agreed on a case-by-case basis. This may be based directly on the cavity counting based assessment of damage, or upon a revised structural assessment using mean data;
- The advised future inspection will usually include UT/MPI plus replication and cavity counting, e.g., at the next outage – but severe cases may call for earlier inspection (e.g., at a refuelling outage). The principle issue is to determine if the weld is degrading;
- In problematical cases, the structural case might be bolstered by a 'safe life' assessment, i.e., assuming a crack and calculating the remaining life on the basis of upper bound creep-fatigue crack growth;
- Ultimately it may be best to replace or repair such items/welds.

In the coarse HAZ region (and more generally) the interest is primarily whether the cavities are extensive enough to become interlinking, forming micro-cracks;

Qu.: How well does R5V7 assessment perform against cavity-based damage?

See Figure 2.

There is a huge amount of scatter.

But note that there are 133 points above the continuous line, but only 9 below. So the R5V7 assessments are generally conservative. (The comparison for hot reheat drain pots is more adverse – i.e., there is a greater proportion of cases where the R5V7 assessment is non-conservative wrt the observed cavitation. This is probably due to coarse HAZ cracking and a failure of the mixed HAZ assessment procedure to be bounding.).

Qu.: TGN043 ensures infrequent failure: is any alleviation possible for “frequent” items?

Yes.

Ref.[28] presents the alleviations to the requirements of TGN043 applicable for items in the “frequent” failure tolerability class. In broad terms this is,

- If the weldment has not previously been inspected, inspection requirements using U/T and MPI shall be as for “infrequent” items, but replication and cavity counting is not required. In particular inspection is required if the operating time at the subsequent statutory outage exceeds 80% of the calculated lower bound creep rupture life for any weldment zone;
- Subject to NDT confirming the item as free of crack-like defects, the safe operating life shall be determined from the shorter of the lives calculated on the basis of, (i) lower bound parent material rupture data, or, (ii)mean rupture data for the other weldment zones (weld material, HAZ, and Type IV region);
- There are two other alleviations compared to the procedure for “infrequent” items: (a) replication, and cavity density counting, is not required, and, (b) the safe-life assessment of postulated defects is not required.

‘Frequent’ items will continue to be subject to speculative inspections at the same level as ‘infrequent’ items.

No difference in assessment requirements applies in the case of crack-like defects being detected.

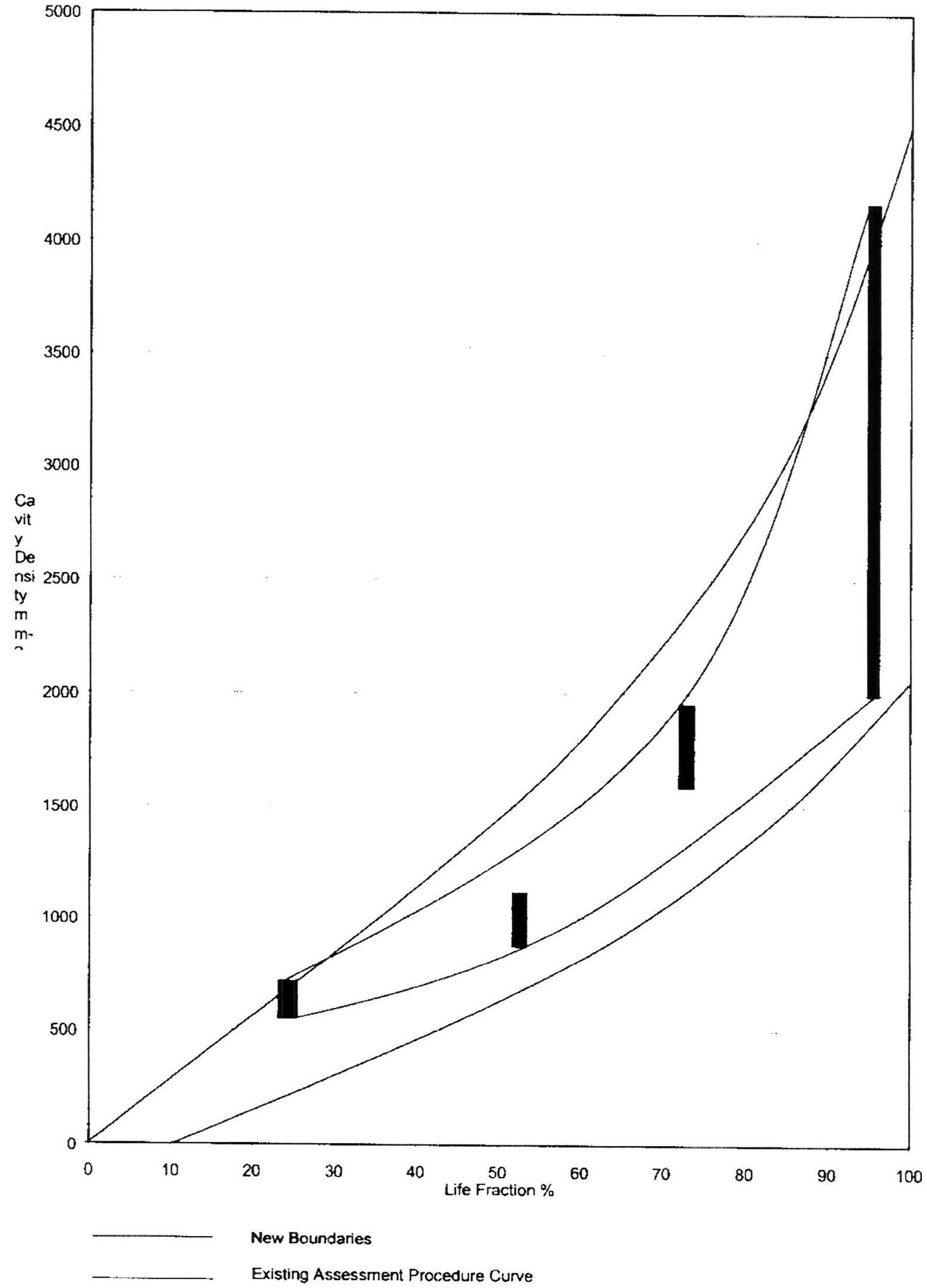
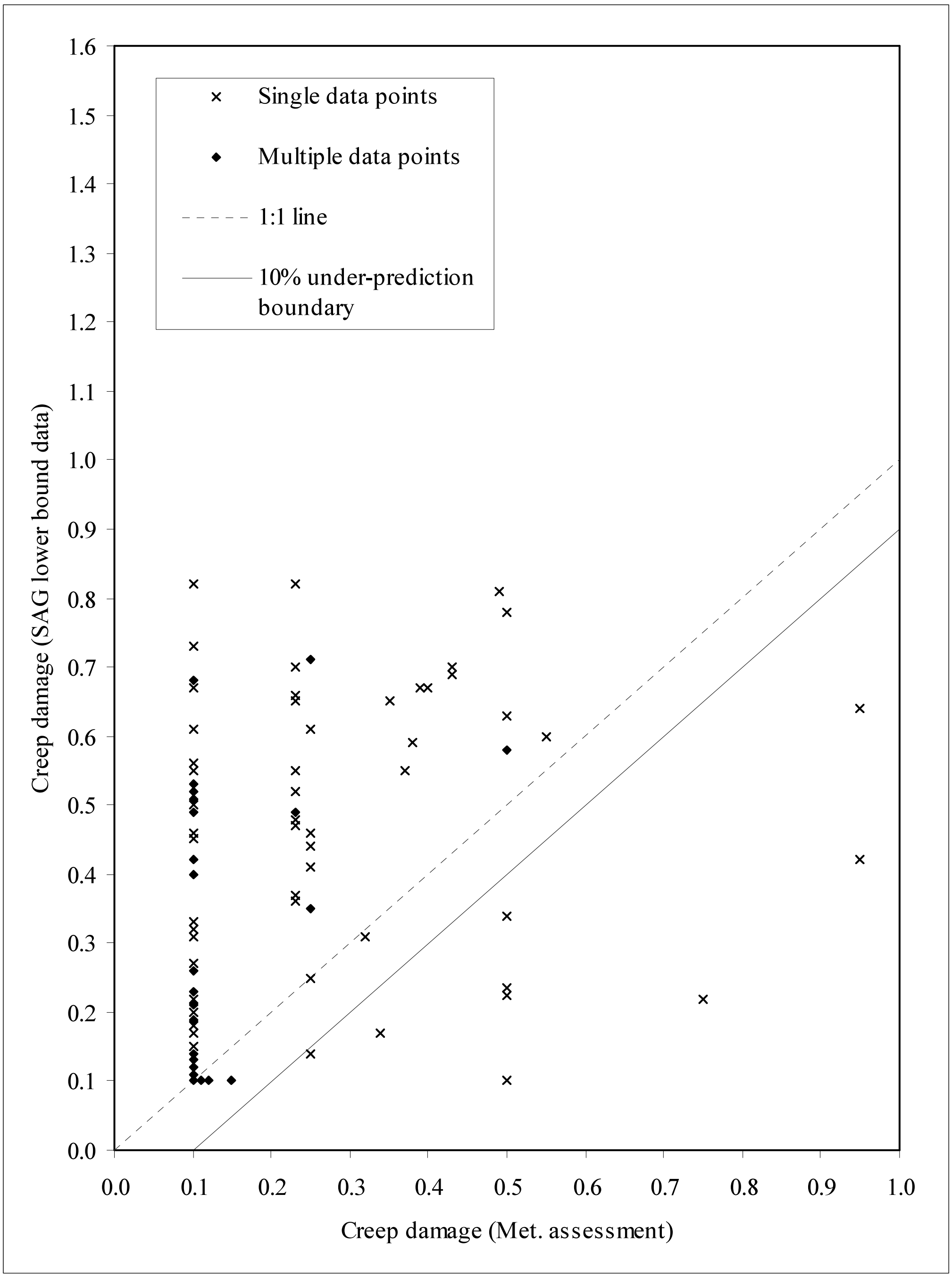

5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Cavity Density mm-2
0
10
20
30
40
50
60
70
80
90
100
Life Fraction %
New Boundaries
Existing Assessment Procedure Curve

Figure 1

Figure 2 – Comparison between measured and predicted damage in welds from the general CMV population across all AGRs (after Tyas, Ref.[29])



133 points above the continuous line, 9 below

TGN044 (Austenitic Pipework)

Qu.: What are the creep-based inspection requirements for austenitic items?

The potential threats due to creep mechanisms are considered to be,

[1] Creep rupture;

[2] Reheat cracking of weldments.

In BE terminology, “reheat cracking” means cracking which develops in-service due, at least in part, to welding residual stresses.

Qu.: Creep-Fatigue?

Oddly, TGN044 does not mention creep-fatigue at all, despite this being one of the more significant cracking mechanisms in austenitic materials. I believe this is based on the absence of identified creep-fatigue cracking on *external pipework and headers* in AGRs - see, however, "HYA/HAR s/h tubeplate upper radii". The tubeplate ligaments are also an area which assessment has suggested to be potentially prone to creep-fatigue cracking.

There may be a case for taking a closer look at risk-based inspection requirements due to creep-fatigue.

This contrasts sharply with austenitic items within the boilers and reactors, where creep-fatigue is generally the No.1 suspect - but this is addressed primarily by CLA. Inspections are not common within the reactors and boilers. One purpose of the CLA process is to raise any requirement for internal inspections arising from creep-fatigue assessments.

Qu.: Cracking of the HYA/HAR Superheater Tubeplate Upper Radii

TGN044, Ref.[2], Appendix B

"During the Heysham 1 R2 2012 statutory outage, cracking was observed on the upper tubeplate radius of a number of superheater headers. Such cracking has been observed previously on many occasions in this area and had historically been diagnosed as SCC and believed to have developed prior to commissioning or during early service. Any such cracking detected during works to replace the superheater headers was removed by excavation prior to remaking the S5 weld. The 2012 observations were novel however in so much as cracking was observed in previously excavated areas, with the implication that it was newly initiated.

A review of the available evidence concluded that the cracking was actually due to a combination of thermal stress during flood-through immediately after a boiler trip and the simultaneous presence of aqueous conditions with high anion and oxygen content giving growth by SCC over a longer time."

TGN044 goes on to describe the safety case commitments to inspect these tubeplate radii. I raise this issue here because I perceive it to be a particular threat, especially in view of the great difficulties that repair or replacement would present.

It may be pertinent to note (and this seems to have been forgotten) that a creep-fatigue assessment carried out in 1996 predicted cracking within a range of times down to as little as ~5 years (i.e., by 2001), Ref.[31]. Moreover, this was based on an assumed creep ductility which we would now regard as closer to best estimate than lower bound. Should we be surprised that cracking re-initiated by 2012? And is the diagnosis of the cracking as SCC, related to the coolant chemistry, correct - or is it simply creep-fatigue?

Qu.: What inspection requirements protect against creep rupture?

The 80% rule, applies, as for CMV. If >80% of the lower bound creep rupture life will be expired by the outage after the outage whose inspection intents are being formulated, then inspection is required. This is rarely the case for austenitic items/welds.

Qu.: What inspection requirements protect against reheat cracking?

TGN044, Ref.[2], classifies welds into three "Levels" for inspection purposes. These Levels are defined by the flowchart of Figure 1 in TGN044, Ref.[2], reproduced as Figure 3 below.

Note that all reported instances of reheat cracking (with one minor exception) have been in welds that are assigned to Level 1. At HYA/HAR there were 2 S5 cracks and 23 S1 cracks, both these welds being butt welds 65mm thick. The first footnote of Figure 3 explains why these are, nevertheless, Level 1, due to the presence of repairs in the two cracked S5 welds, and the repeated re-makes of the S1 welds without prior HAZ removal.

The inspection requirements specified in the current TGN044, Ref.[2], are,

Infrequent Failure Welds

- Level 1(a): Maintain fracture mechanics assessment for the growth of reheat cracks. Re-inspect before end of life (or 50% of life for butt welds, if repairs of unknown depth are potentially present), subject to a minimum sample of 10% per outage.
- Level 1(b): Inspect at a minimum level of 10% per outage.
- Level 2: Inspect at a minimum level of 5% per outage.
- Level 3: no inspections.
- If there are welds on the pipework of the particular reactor that have been retrospectively heat treated at 750ºC, inspect one such weld per outage. This is designed to provide further confidence in the efficacy of such heat treatments. Ideally, the weld would have been in Level 1 prior to the heat treatment.

Frequent Failure Welds

- Level 1(a): Maintain fracture mechanics assessments for the growth of reheat cracks. Inspect at a minimum level of 5% per outage.
- Level 1(b): Inspect at a minimum level of 5% per outage.
- Level 2: assess the need for any inspections case-by-case.
- Level 3: no inspections.

All newly introduced Level 1 welds and any Infrequent Level 2 welds should have an initial in-service inspection ideally after six years, although the precise timing may reflect individual circumstances.

Qu.: Previous Inspection Requirements

In the last (2010) version of these lecture notes, I included the following opinion,

"*Reheat cracking is an early to mid life phenomenon. Consequently it is very unlikely that reheat cracks will now appear in welds which have previously been inspected after significant service exposure and shown to be clear. The inspection policy could therefore be relaxed (in my opinion).*"

The first sentence really meant, *Reheat cracking is an early to mid life phenomenon* ***in 300-series steel weldments***. In materials with slower creep rates, the timescale can be extended accordingly, Esshete 1250 being a case in point. However, since 2010 the inspection requirements have indeed been relaxed. For example, for Level 1 the previous minimum sample was 25% per outage but is now 10%, and for Level 2 the previous minimum sample was 10% per outage but is now 5%. (Earlier requirements also alluded to certain "baseline inspections" which I presume are long since completed).

Qu.: What are the non-creep based inspection requirements in TGN044?

The broad categories of the non-creep requirements are,

- ‘Original sin’ inspections
- Environmentally assisted cracking (EAC) inspections;
- Thermal fatigue cracking inspections;
- Speculative inspections.

Specific ‘original sin’ mechanisms considered include WSIC (weld strain induced cracking) and stress relief cracking (which occurs during PWHT).

EAC subsumes corrosion pitting, IGA (inter-granular attack) and SCC (stress corrosion cracking), of which the latter is the most virulent mechanism. See TGN044 for details.

The thermal fatigue threat is of two types: small bore and thick section.

Thermal fatigue is normally associated with thick sections, being due to thermal transients which produce larger stresses in thicker components. Austenitics are particularly susceptible due to their lower thermal conductivity compared with ferritic materials (which increases the peak transient temperature gradients), as well as their larger coefficient of thermal expansion. The areas potentially at risk of thermal fatigue cracking are discussed in TGN044.

Qu.: What is "small bore branch thermal fatigue cracking"?

Small bore thermal fatigue relates to small bore branches off larger bore pipelines containing superheated steam (i.e., main steam or hot reheat). It occurs when condensate continually forms in the small bore branch line and repeatedly quenches the region around the branch connection, leading to cracks which are radial with respect to the branch at this position. There is a simple model of this phenomenon on my web site here: http://rickbradford.co.uk/SmallBoreThermalFatigue.pdf.

Qu.: Are generic levels of speculative inspection specified in TGN044?

No.

Unlike TGN043 for CMV, for austenitic pipework any requirements for speculative inspection is Station-specific.

In fact, the austenitic inspection requirements generally are much more Station-specific than for CMV. For this reason, TGN044 contains detailed Station-specific Appendices in which the inspection requirements are itemised. This makes it difficult to summarise the requirements simply.

However, there are specific requirements to inspect due to ‘original sin’ and EAC issues, particularly at DNB/HYA/HRA.

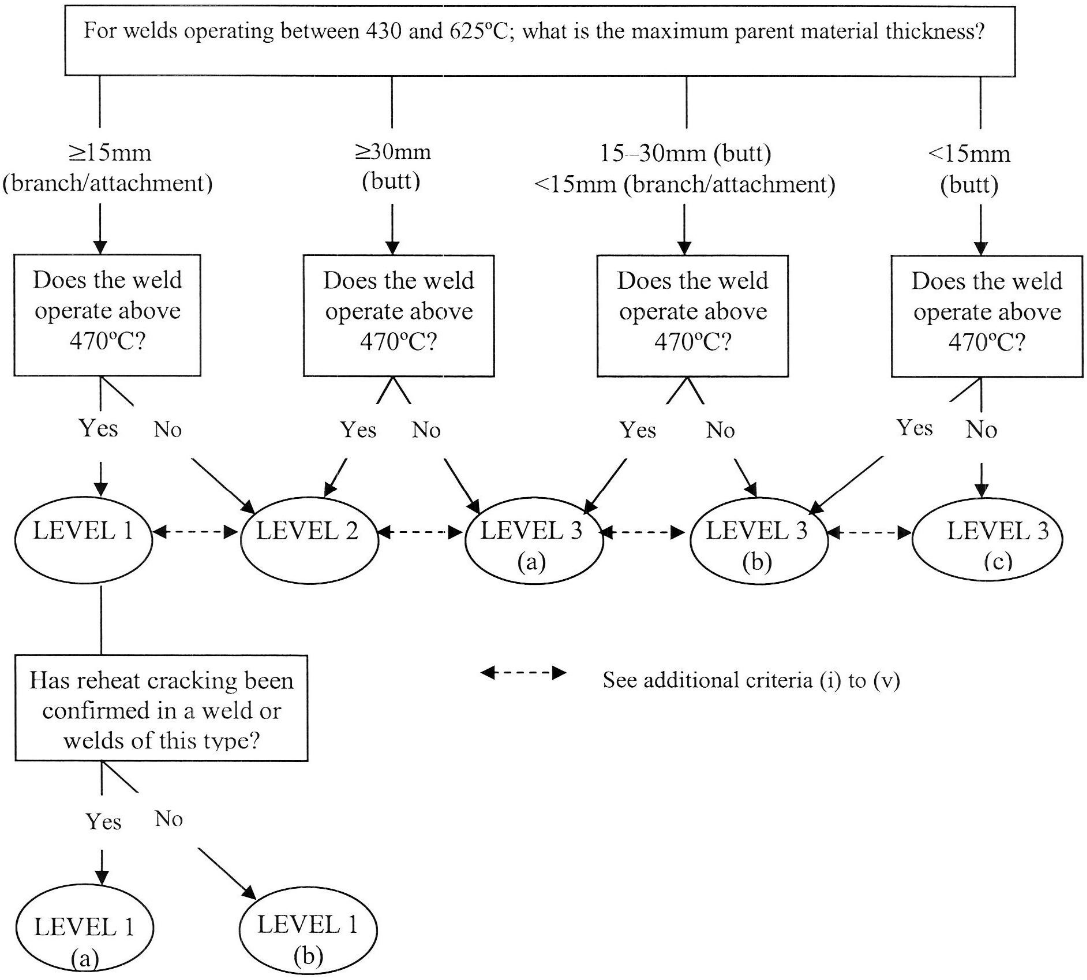
Qu.: How important are creep issues to the inspection regime?

As a rough guide, creep issues are less significant to the inspection regime for F/IF items on austenitic pipework than other mechanisms - now that the reheat cracking threat has subsided (for 300-series steels, at least). However, creep issues become important for IOF/IOGF/HI items in austenitic pipework due to the requirement for safe lives (crack growth assessments) to define inspection intervals.

Qu.: What exactly does “dye penetrant inspection” mean in TGN044?

TGN044 states, “Where DPI is specified, in all cases this involves the use of colour-contrast (rather than fluorescent) dyes. I've no idea why, fluorescent can be better.

Figure 3: Flowchart defining inspections levels from TGN044



Additional Criteria

(i) For butt welds, go to next highest level if one or more of the following features are present, or cannot be guaranteed to be absent:
- Local repairs.
- Fully re-made weld in which the previous strain affected zone was not fully removed.
- Weld buttering adjacent to the main weld, resulting from over-capping or other reasons.

(ii) For butt welds, go to the next highest level if a significant stress-raising feature is actually, potentially or historically present, and/or high system stresses are acting. This should be applied in addition to (i), as appropriate.

(iii) As-welded repairs or buttering applied to solution heat treated welds or parent metal should be treated as repaired as-welded welds.

(iv) Go to the next lowest level if the parent material is Type 316L steel.

(v) Go to the next lowest level if heat treated at ≥680°C. If heat treated at ≥750°C, regard as non-susceptible.

(vi) Any weld type in which reheat cracking is newly confirmed becomes Level 1(a).

(vii) Welds currently operating <470°C but historically >470°C require individual consideration.

"Next level" means, for example, 3(c) to 3(b), 3(a) to 2, 2 to 1.

Ref.[2], Figure 1 : Flow chart for determining inspection levels for austenitic reheat cracking

TGN046 (Transition Joints)

Qu.: What are the creep-based inspection requirements for Infrequent TJs?

The use of R5V6 to evaluate a transition joint lifetime / damage fraction is central to the inspection policy of TGN046. Inspection is required based on the 80% rule as used also in TGN043 and TGN044: Inspection is required at the outage before the outage in which the life usage first exceeds 80%.

In addition, at the outage before the outage in which the life usage first exceeds 50%, a speculative sample of 5% of any “infrequent” population of TJs shall be inspected. Prior to this time any “infrequent” population of TJs shall be subject to a 2% speculative inspection sample.

Qu.: What are the creep-based inspection requirements for Frequent TJs?

Inspection is required at the outage before the outage in which the life usage first exceeds 80% as for infrequent TJs.

In addition, at the outage before the outage in which the life usage first exceeds 50%, a speculative sample of 5% of any “infrequent” population of TJs shall be inspected, though this may be reduced to 2% if justified explicitly. Prior to this time no inspections of “frequent” TJs is required.

Qu.: What are the other (non-creep) inspection requirements for TJs?

In principle these might include,

- ‘Original sin’ inspections
- Environmentally assisted cracking (EAC) inspections;
- Thermal fatigue cracking inspections;

However, EAC issues are effectively covered by TGN044 which automatically applies to the austenitic side.

Transition joints are invariably butt welds, not feature welds, or fillet welds, and in particular they do not occur at branches. Consequently thermal fatigue is unlikely to be an issue (and in as far as it might be, it is included in the R5V6 assessments).

Consequently there are no other inspection requirements in TGN046.

Qu.: What inspection techniques are to be used?

TGN046 states,

Wherever possible, components should be subject to full surface and volumetric inspection. However, it is acknowledged that the geometry of certain smaller components may be such that it is only practicable to undertake surface inspection. In addition, it is not considered to be reasonably practicable to carry out surface inspection in situations where the volumetric inspection is conducted from the internal surface (e.g. HPB/HNB reheater outlet penetrations). The principal NDT techniques for transition joints are dye penetrant inspection (DPI) and ultrasonic testing (UT). In practice, the precise NDT procedures and techniques to be utilised for any given component shall be confirmed by Inspection Group personnel.

Metallographic replication may be utilised to diagnose defect indications revealed by surface inspection.

Qu.: Are material confirmation checks required?

Yes. TGN046 states,

There is a requirement to ensure that components are fabricated from the correct materials. For in-service components, this may be confirmed from original construction records or documentation showing the results of checks performed during the subsequent operating history. Where neither of these is in place, components selected for inspection should be subject to chemical analysis covering the parent materials and any weld metal present.

The inspection of all new transition joints introduced into plant systems, whether complete replacements or local repairs, and any previously unrecorded welds should also include confirmation of materials.

References

This is not a complete list of all TGNs, CTSs & BEOMs, but just the ones of greatest interest to us. I believe these are the most recent revisions as of January 2015 except for those shaded which I did not check for updates. Those relating to systems where inspection guidelines could be controlled by creep issues are shown in **bold text**. *I have not checked that the items in blue do not include requirements based on creep issues. This would bear checking.*

[1] **M.P.England, "TGN 043 – Guidelines for the Inspection of CMV Pipework Systems on AGR Plant", BEG/SPEC/ENG/TGN/043, Rev.002, February 2013**.

[2] **D.P.Neale, "Technical Guidance Note 044 Guidelines for the Inspection of Austenitic Stainless Steel Steam Pipework and Headers on AGR Plant", BEG/SPEC/ENG/TGN/044, Rev.005, June 2013**.

[3] D.P.Neale, "TGN 045 - Inspection Guidelines for Valves in Main Steam, Hot Reheat and Carbon Steel Steam Pipework Systems on AGR Plant", BEG/SPEC/ENG/TGN/045, Rev.001, June 2011.

[4] **R.A.Stevens, "TGN 046 - Guidelines for the Inspection of Transition Joints on AGR Plant", BEG/SPEC/ENG/TGN/046, Rev.001, January 2013**.

[5] J.P.Cockerline, "TGN 048 - Guidelines for the Inspection of Carbon Steel Steam Pipework Systems on AGR Plant", BEG/SPEC/ENG/TGN/048, Rev.003, June 2014.

[6] S.M.Chilcott, "TGN 049 - Guidance for the Inspection of Decay Heat Systems on AGR Plant", BEG/SPEC/ENG/TGN/049, Rev.001, March 2013.

[7] D.P.Neale, "TGN 050 - Inspection Guidelines for Low Pressure Vent and Emptying Vessel Systems on AGR Plant", BEG/SPEC/ENG/TGN/050, Rev.002, January 2013.

[8] R.A.Stevens, "TGN 051 - Guidelines for the Inspection of Flexible Hoses in Steam System Safety Relief Valve Discharge Pipework on AGR Plant", BEG/SPEC/ENG/TGN/051, Rev.003, May 2011.

[9] R.S.Gill, "Guidance for TGN 052 - Inspection Guidelines for Main Turbine Steam Chests and Emergency Stop and Governor Valve Bodies on AGR Plant", BEG/SPEC/ENG/TGN/052, March 2010.

[10] R.S.Gill, "Guidance for TGN 053 - Inspection Guidelines for Main Turbine Pressure Casings on AGR Plant", BEG/SPEC/ENG/TGN/053, March 2010.

[11] R.S.Gill, "Guidance for TGN 054 – Inspection Guidelines for Boiler Feed Pump Turbines on AGR Plant", BEG/SPEC/ENG/TGN/054, March 2010.

[12] D.Reid-Hutchings, "TGN 055 – Inspection Guidelines for Deaerators on AGR Plant", BEG/SPEC/ENG/TGN/055, May 2010.

[13] D.Reid-Hutchings, "TGN 056 - Inspection Guidelines for Reactor Start-Up Vessels on AGR Plant", BEG/SPEC/ENG/TGN/056, May 2010.

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[15] Belinda E. Fitzgerald, "Inspection Guidelines for Turbine Ancillary Pipework on AGR Plant", BEG/SPEC/ENG/TGN/058, Rev.002, April 2012.

[16] S.A.Urmston, "TGN061 - The Management of Engineering Technology Branch's Outage Related Inspection and Assessment Activities", Rev.004, BEG/SPEC/ENG/TGN/061, June 2014.

[17] C.G.Love, "TGN063 – Guidance for Determining and Assessing the Risk from External Degradation Mechanisms of Pipework Systems at British Energy Power Stations", BEG/SPEC/ENG/TGN/063, Rev.001, October 2012.

[18] D Crowle, "TGN 080 – The Selection, Care and Replacement of Threaded Fasteners in Fluid Containing Systems Operating at Temperatures below 375ºC", BEG/SPEC/ENG/TGN/080, Rev.003, January 2013. See also…

[19] D Crowle & D Reid-Hutchings, "CTS 104 – The Selection, Care and Replacement of Threaded Fasteners in Fluid Containing Systems Operating at Temperatures Below 375°C", BEG/SPEC/ENG/CTS/104.

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[23] T.P.T.Soanes, "Guidelines for a Flow Accelerated Corrosion Inspection Programme at Advanced Gas Cooled (AGR) Reactors", BEG/SPEC/ENG/TGN/092, Rev.001, February 2011.

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