NUCLEAR SAFETY DIRECTORATE - BUSINESS MANAGEMENT SYSTEM		
TECHNICAL ASSESSMENT GUIDE **GRAPHITE REACTOR CORES**		**T/AST/029**
		ISSUE 002
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Contents

1. Purpose and scope

1.1 The purpose of this Technical Assessment Guide (TAG) is to provide additional guidance, interpretation and explain the application of HSE's Safety Assessment Principles for Nuclear Plant, 1992 [1] (SAPs), to the assessment of graphite component and core behaviour for new and operating gas-cooled reactors, and some aspects of reactor decommissioning and radioactive waste storage.

1.2 This TAG contains *guidance* to advise and inform NSD inspectors in the exercise of their professional regulatory judgement. Assessors will need to use this TAG in combination with their existing experience and through discussion with peers in NII to develop their understanding of the breadth and depth of aspects of the NII assessment process in this technical area. This document is not written as a guide to licensees on how to develop their safety cases.

1.3 The outcome of an assessment is predominantly a consequence of the inspector's professional regulatory judgement and discretion, within the framework of NII's assessment process. Assessment of a graphite core safety case should not be undertaken in isolation. In particular there are other TAGs, which may be relevant in particular, cases and this is dealt with in the Introduction below.

1.4 Comments on this guide, and suggestions for future revisions, should be recorded on the appropriate registry file.

2. SAPs addressed

2.1 The NII's Safety Assessment Principles form a framework that can be referred to by assessors when making technical judgements. Attention is drawn to Paragraph 10 of the SAPs that discusses application to existing plant.

2.2 The key section of the SAPs is the Reactor Core and paragraphs 332 to 347 sets out the philosophy for assessment of reactor cores. SAPs P260 to P274 are applicable with the exception of P267 and P273. Other relevant SAPs are: P21, P40, P54, P66-P72, P76, P79, P80, P82-P90, P97-P99, P101-P103, P114-P116, P119-P122, P125,

P128-P131, P145-P147, P154-P157, P160, P162, P163, P165-P167, P315-P323, P325-P327 and P329.

3. Relationship to licence and other relevant legislation

3.1 The primary licence conditions for which assessments of the safety of graphite cores are to be carried out are:

LC 15 Periodic Review;
LC 19 Construction or Installation of New Plant;
LC 20 Modification to Design of Plant Under Construction;
LC 21 Commissioning;
LC 22 Modification or Experiment On Existing Plant;
LC 23 Operating Rules;
LC 24 Operating Instructions;
LC 26 Control and Supervision of Operations;
LC 27 Safety Mechanisms, Devices and Circuits;
LC 28 Examination, Inspection, Maintenance and Testing;
LC 30 Periodic Shutdown;
LC 35 Decommissioning.

3.2 A range of other licence conditions may be relevant to assessment of graphite reactor core safety cases, these include:

LC 6 Documents, Records, Authorities and Certificates;
LC 10 Training;
LC 12 Duly Authorised and Other Suitably Qualified and Experienced Persons;
LC 13 Nuclear Safety Committee;
LC 14 Safety Documentation;
LC 17 Quality Assurance;
LC 25 Operational Records;
LC 29 Duty to Carry Out Tests, Inspections and Examinations;
LC 31 Shutdown of Specified Operations;
LC 36 Control of Organisational Change.

4. Advice to assessors

4.1 Introduction

1) All the operating UK gas-cooled reactors have graphite cores. In addition, a number of reactors with graphite cores or reflectors are being decommissioned. These include research, power and isotope production reactors.
2) Facilities at a range of nuclear power generation and chemical plant facilities are used to store irradiated graphite waste. Some decommissioning reactors and waste stores also contain irradiated graphite.
3) This Guide principally covers graphite cores in operating reactors and to a lesser extent decommissioning stations. It

develops an approach towards assessment of ageing and other service induced changes.

4) Whilst there are some similarities in the approach to assessment of graphite core functionality for operating reactors and structural integrity assessment, as outlined in Technical Assessment Guide T/AST/016[2], there are subtle and sometimes significant differences. As a result this Guide need not be read in conjunction with T/AST/016 regarding structural integrity aspects of the safety case. This TAG explains the philosophy, identifies pertinent aspects of the SAPs and develops guidance in the context of a graphite core assessment.

5) It is important to be aware of the context of the graphite core safety functionality aspect of the safety case in relation to other aspects of the safety case. A safety case will usually be dealing with some hazard that would have some undesirable consequence. The current Probabilistic Safety Analyses (PSA) for gas-cooled reactors assume implicitly that the failure of the graphite core to fulfil its safety functions is so low as to be incredible, that is there is no implicit fault frequency arising from the core failing to fulfil it safety functions.

6) Graphite core safety functionality assessment relies on a number of inter-related technical areas, for example neutron dosimetry, materials science and irradiation damage behaviour of graphite, mechanical and physical property testing, radiation gas chemistry, thermo-hydraulics, stress analysis, whole core modelling, inspection techniques. Whilst assessors may be experienced in a number of these areas, the assessor should be alert to those aspects of an assessment where they may need to consult with colleagues or seek advice external to HSE. Assessors should also avoid giving undue attention to those aspects with which they are most familiar as it is unlikely that a core safety case could be made on one feature alone. It is likely that on most occasions it will be necessary to consult with colleagues assessing PSA / fault studies aspects of the safety case to consider the impact of the core case on initiating faults.

4.2 Reactor core design

1) In both Magnox and AGR reactors the graphite core design provides: neutron moderation; neutron efficiency by neutron reflection; forms the passages for entry and movement of control rods and fuel within the core; and the graphite components provide the structure and direct coolant flow for fuel and core cooling.

2) The designs of the graphite cores of the UK gas-cooled reactors were not based on any recognised published design code.

4.3 Safety functions of a graphite core during the operational phase

1) The safety functions of a graphite core in UK gas-cooled reactors are to:

- i) enable shutdown and reactivity control post shutdown;

ii) allow fuel and core cooling functions to work during operation, transients, faults and post shutdown;

iii) avoid challenges to fuel integrity through core physical changes and responses;

iv) enable removal of fuel from the reactor.

2) The graphite reflector surrounding the active core reflects neutrons back into the core for reasons of neutron and fuel economy and aids the maintenance of criticality. It also reduces the energy of neutrons escaping from a core and thereby limits damage to the core restraint, core support and where applicable the steel Reactor Pressure Vessel.

4.4 Safety and functional requirements of graphite sleeves

1) Graphite sleeves are employed in some later designs of gas-cooled reactors as an integral part of the fuel element design and form the structure of the fuel stringer to secure re-entrant flow. These are replaced when the fuel is replaced. The key safety functions of such graphite sleeves are:

i) To separate the main coolant and re-entrant coolant flows to ensure fuel, fuel stringer component and core cooling.

ii) To remain intact, both whilst within the core and during refuelling. To avoid generation of debris that could interfere with fuel and core cooling and not prejudice fuel integrity arising from sleeve failure.

2) Graphite sleeves are also employed in some early station designs to elevate graphite brick temperatures to reduce dimensional changes and stored energy due to neutron damage. Sleeves should retain adequate location and integrity to secure adequate fuel and core cooling.

4.5 Philosophy of graphite core safety functionality assessment and safety categorisation

1) The general lack of reliability data for nuclear graphite structural components leads to assessment being based primarily on established deterministic engineering practice. Even when there is some confidence in assessing reliability on the basis of existing data and a probabilistic safety case is possible, it is unlikely to be acceptable without substantial support from theoretical analyses and engineering judgement. As a result, although the radiological consequences of failure of structural components may be significant, it is often not possible to reliably estimate the risk for inclusion in the probabilistic safety analysis.

2) SAP P21 requires that the safety case should present a list of all initiating faults which are included within the design basis of the plant. All initiating faults should be considered, but failures of structures, systems or components, for which acceptable special case arguments have been made in accordance with SAP P70 need not.

3) SAP P40 notes that for some fault sequences, it will not be possible to calculate the frequency of occurrence because the data are inadequate or no appropriate models are available. The

graphite core is in this category. However, SAP P40 requires that in all such cases, a considered judgement should be made of the contribution to the predicted frequencies from such faults. The assessor, in reaching a judgement on the adequacy of the safety case, should consider the contribution of core related initiating faults and seek advice from PSA and fault studies assessors of the impact on the PSA and fault sequences.

4) The graphite core forms a principal means of ensuring nuclear safety as it has the potential to affect fuel cooling, fuel integrity, and reactor shutdown and hold-down. As a result the safety categorisation of the moderator and associated components would normally be expected to be safety Category 1 (SAP P69).

5) In general the safety functional requirement of structures will depend on the potential radiological consequences of their failure, and on the requirement to meet the functional requirement for the proposed life of the facility. From this, the appropriate standards of design, manufacture, installation and testing, and in-service maintenance, inspection and testing of structural components can be derived. The assessor should therefore verify the potential radiological consequences of component and core damage at an early stage in the assessment process to enable the depth and breadth of the assessment to be established. In this process it is also important to identify the potential failure modes of the component. The failure modes should be ranked in terms of their significance and consequences.

6) P69 requires that structures, systems and components should be categorised on the basis of the consequences of failure and of the failure frequency requirements of the safety case. P83 then suggests appropriate safety case requirements, and thus assessment requirements.

7) The safety case for structures and components should be examined in the context of the overall safety case for the plant, taking due account of interactions with other safety features. It may be that there are protective devices that can mitigate the effect of component and core damage to a greater or lesser degree. It may be that the direct effect of structural failure is trivial but the consequences may be failure of safety related plant, instrumentation, or operator dose uptake, i.e. the failed part acts as an internal hazard to the principal safety feature. The consequences of component and core damage may result in secondary damage to the principal safety protection features of the plant, in which case recourse to the Special Case Procedure may be appropriate.

8) SAP P61 requires that potential hazards from operation should be identified. Hazard is defined in the SAPs as "an internal or external event with the potential to cause equipment

damage or failure in the plant". Damaged graphite components have the potential to impair or result in failure of the core to passively perform its safety functions. In this respect graphite component damage, such as moderator brick cracking, should be treated as a hazard, or a precursor to an initiating event.

Special Case Procedure

9) Reference is made, in paragraph 117 (P70) of the SAPs, to those special cases where the component forms a principal means of ensuring nuclear safety, but there is inadequate reliability data. The graphite core is such an example. The procedure requires a comprehensive examination of all relevant scientific and technical issues, taking account as appropriate of precedents set under comparable circumstances in the past.

10) The assessor should establish that resort to the special case procedure is justified, for the particular safety case, on the basis of judgement derived from application of the preceding paragraphs.

11) Paragraph 201 of the SAPs refers to paragraph 117 (P70) and to those special cases where the component forms a principal means of ensuring nuclear safety. For such components the SAPs note that there are two particularly important aspects to be addressed: that the structure should be as defect free as possible, and that it should be demonstrated to be defect tolerant. This wording is of course in terms of crack-like defects but can be generalised to other forms of degradation. And in principle, a component could fail due to overload without any contribution from degradation in the fabric of the component. In order to achieve these fundamental requirements, several related but independent arguments should be used, based on the following (SAPs Para. 201):

> i) the use of sound design concepts and proven design features;
>
> ii) the analysis of the potential failure modes for all conditions arising from design basis faults;
>
> iii) the use of proven materials;
>
> iv) the application of high standards of manufacture, including in-process inspection, and construction, for the materials and processes used;
>
> v) high standards of quality assurance throughout all stages of design, procurement, manufacture, construction and operation;

vi) pre-service and in-service inspection to detect defects and component damage at sizes below those which have the potential for causing or developing into a failure mode, and to size these defects conservatively;

vii) the provision of in-service plant and materials monitoring.

12) These requirements, which were developed primarily for steel structural components, whilst applicable to a graphite core and its component parts require interpretation of the philosophy, purpose and meaning for a graphite core. The following sections of this TAG provide this interpretation.

13) Some graphite components may be predicted to sustain damage during reactor operating lifetimes. Under such circumstances the assessor needs to establish if core safety functionality is maintained and demonstrated throughout the projected operating life or throughout an appropriate operating period. In reaching a judgement on the adequacy of a safety case the assessor needs to consider whether any component damage is random or systematic. Whether such component and core damage may increase with continued operation, the rate of damage, and the temporal and spatial distributions. The following approach may be used to assist in determining the adequacy of a safety case where component damage is predicted and in particular where such damage may increase with continued operation. Where there is an increasing likelihood of challenge to core safety functions (that is increasing degree of component and core damage with time) then the burden of proof and the robustness of the safety case should increase to meet this challenge. "Damage" in this context, and in following sections, refers to macroscopic component defectiveness as well as deterioration of relevant material properties arising from ageing processes.

Limit of Tolerability

14) The following sections provide guidance on what can be expected for a core safety case where component and core damage is predicted, or observed, to achieve a "broadly acceptable" (and probably demonstrate "negligible risk"). However, a safety case may still be adequate to secure operation in the short term whilst ALARP improvements are made. This section discusses the absolute minimum requirements for a core safety case (ie at the "limit of tolerability") to secure operation until such time that ALARP improvements are made or continued operation may no longer be justified. The following list is in particular applicable to a reactor that is currently operating. For a reactor that is shutdown then it may be reasonably practicable to undertake examination, inspection, surveillance, sampling and testing before restart for a

case judged to be at the limit of tolerability. The suggested set of minimum conditions to achieve a just tolerable core safety case are:

- i) Maintenance of graphite component and core geometry to secure sufficient fuel and core cooling (SAP P264).
- ii) Minimisation of the chance of core, and fuel damage, as a result of over-heating (SAP P264).
- iii) Safe shutdown and hold-down should not be inhibited by graphite component and core damage (SAP P265).
- iv) Adequate monitoring of safety related conditions (SAP P268).
- v) Fuel can be safely removed from the core (SAP P273).

4.6 Multi-legged graphite core safety case

1) Multi-legged safety cases are often presented for components where the Special Case Procedure is applied, such as a steel Reactor Pressure Vessel safety case. This section discusses possible legs of a graphite core safety case and how the assessor may judge the contribution of each leg to the overall safety case. The structure presented is intended as a framework for the assessor to aid their understanding of a core safety case, its strengths and weaknesses and what areas could be explored to secure an ALARP graphite core safety case. Significant professional judgement will be necessary to establish the adequacy of a graphite core safety case; exercise of regulatory discretion is requisite to determine whether all the elements of the framework or a sub-set are adequate to secure an ALARP graphite core safety case.

2) NII's strategy (3) to secure adequate and ALARP graphite core safety cases presents the recommended framework to address perceived challenges to component and core integrity from graphite ageing and gives examples of precedent from previous assessments of core safety cases. The report identified the following possible legs of a graphite core safety case and considered the contribution to ALARP of multi-legged graphite core safety cases.

- i) Design;
- ii) Manufacture, construction and commissioning;
- iii) Component and core condition assessment;
- iv) Damage tolerance assessment;
- v) Analysis of consequences of core ageing on fuel and core cooling, shutdown, hold-down and fuel integrity;
- vi) Monitoring;
- vii) Examination, inspection, surveillance, sampling and testing;

3) The structure of each leg is discussed in subsequent sections and the associated SAPs identified and further guidance provided.

4) Where a multi-legged safety case is possible and the legs of the case are independent then a weakness in one of the legs

may be off-set by a stronger leg of the safety case. A strong leg may be used to underpin another leg. The strength of each leg may vary through life and ALARP improvements may include consideration of how increased confidence may be achieved and demonstrated from each leg of the safety case.

5) In consideration of an apparent multi-legged safety case the assessor needs to establish if each leg is independent. The most robust case would be one where all legs are independent and there is redundancy and diversity in the arguments presented. If more than one leg is underpinned by common data, assumptions or methodologies then the strength of a multi-legged case may be undermined.

4.7 Hazard and reliability

1) In reaching a judgement on the adequacy of a core safety case the assessor needs to establish in broad terms what are the likely implications of the core failing to perform its safety function in terms of radioactive release and reach a judgement on the probability of its occurrence, SAP P114.

2) Section 4.5 discussed the contribution of the passive safety functions of the core to the probability and magnitude of a radioactive release, through the PSA and fault analysis, where core safety functionality is challenged through a range of possible or predicted failure modes. This section provides guidance on how to assess the likely hazard, likelihood of realisation of the hazard and consequences of component and core damage.

3) For a core safety case the assessor needs to consider for each component and core damage mechanism whether damage is due to ageing or whether damage may occur at any stage of life. The latter is potentially easier to address as the likelihood, by definition, is not increasing with time. Whereas for age-related phenomena the likelihood of a challenge to core safety functions will increase with time, therefore assigning a failure probability is difficult. The starting point is to identify damage mechanisms and how these may impact on core safety functions, ie determine the likely hazard. A conservative estimate of probability of core safety functions being affected, over a defined period, is also required together with a consideration of consequences. Inspection and monitoring will be necessary to ensure that the estimates are conservative.

4) Any novel design features, or degraded core condition, where there is little or no experience, for the operating regime (in terms of exposure conditions and component and core condition) require careful consideration. Prior acceptable behaviour should not necessarily be used as a guide to future performance. The other factors that need to be considered are the operating environment, uncertainties in operating and fault conditions, physical data and design methods (SAP P114). Where operating experience is available for nominally identical or similar graphite component and core designs, exposed under

identical or similar conditions, employing identical or similar materials, then some degree of assurance may be obtained of the likely component and core reliability where operation bounds that of the components and core of interest. However, it is important that uncertainties in as-manufactured condition, effect of exposure conditions, and in particular fault conditions are demonstrated to be applicable. Where appeal is made to operating experience of a different component or core if that core has not experienced similar operating conditions, transients or faults that could impact on component or core damage, and hence likelihood of challenges to safety functionality, then care needs to be exercised in direct application of reliability and performance data (SAP P116). Appropriate measures should be taken to ensure that the onset of component and core damage can be detected, and that the consequences of such damage are acceptable and minimised. This aspect is discussed under Section 4.13, 4.14 and 4.15.

5) SAP P119 requires, for all hazards, that the design basis analysis principles and the PSA principles are satisfied as appropriate, unless it can be demonstrated that the frequency of an event being exceeded is less than once in 10 million years, or if the source of the hazard is sufficiently distant that it cannot reasonably be expected to affect the plant. This therefore means that the assessor, unless it can be demonstrated that the frequency of the core failing to perform its passive safety functions is essentially incredible, should consult colleagues assessing the PSA and fault studies to investigate the impact of the core on overall plant risk.

4.8 Quality Assurance

- high standards of quality assurance throughout all stages of design, procurement, manufacture, construction and operation, SAPs Para. 201(e).

1) The licensee should use and require its contractors to use formal QA procedures to specify the quality and organisational arrangements for each stage of the design, manufacture, installation, operation and decommissioning. The QA programme should be sufficient to justify the reliabilities claimed for the structure in the safety case. If judged appropriate QA arrangements should include provision for the appointment of a Third Party Inspection or Qualification Agency. The aim should be to provide confidence that the safety case requirements have been met by close control and surveillance of the design, manufacture, operation and maintenance activities. From past experience of where issues can arise, the assessor may wish to check the licensee-contractor interface of the QA procedures.

2) The QA arrangements should include a concessions procedure so that departures from design, specification of materials, manufacturing processes, dimensional tolerances, defects etc., can be identified and appropriate consideration given to the safety significance of such departures. It should be demonstrated and recorded that the structure is capable of meeting its safety functional requirements despite these departures from specification (P157). To provide confidence in the quality of the design, manufacture, inspection and testing, the assessor should consider examining the concessions system on a sample basis. A review of the case history or lifetime records (the terms vary among licensees) may be appropriate during manufacture of new structures, during periodic reviews or discovery of unexpected defects in existing structures, to verify that any concessions granted do not invalidate the safety case requirements or assumptions.

3) When structures provide the principal means of ensuring nuclear safety the highest standard of design and construction is required. The assessor may need to examine the case history to verify that it contains adequate records of the specification of detailed component design, in-process inspection and testing and inspection procedures. Examination of the construction case histories can provide confidence in the original manufacturing quality. Nevertheless, original construction records do not always show the full picture, and the assessor may need to consider other options, such as inspection.

4) The assessor may wish to sample the licensee's quality arrangements for production of the safety case itself. The safety case production process must have a reliability commensurate with its conclusions regarding the risk for the component or system addressed. For complex, multi-disciplinary safety cases the assessor may wish to consider communication of information between disciplines and the handling of issues generated during the production of the safety case (P315-322 as they relate to production of safety cases and the link between safety case assumptions / claims and actual plant condition / operation).

4.9 Design

- the use of sound design concepts and proven design features, SAPs Para. 201(a)

1) Structures should be designed such that failure modes are progressive and sufficient warning of impending

failure is provided to enable remedial measures to be taken to prevent failure or to mitigate its consequences.

2) SAP P260 requires that the reactor core design takes account of all operating modes including normal operation, re-fuelling, testing, shutdown and fault conditions. The design of the core should take account of all identifiable environmental effects including irradiation, chemical and physical processes, and static and dynamic mechanical loads; and also of thermal distortion, thermally-induced stress, possible variations in manufacture and any other identified safety-related factor. The design should demonstrate tolerance of the core safety functions to such ageing processes and loads imposed on its components and structure. This is considered further at Section 4.11.

3) All components of the core should be mutually compatible and compatible with the remainder of the plant, SAP P266. The design should ensure that core component (including fuel etc) interactions (chemical and mechanical) do not prejudice the safety functions of the graphite core or other core components.

4) To demonstrate that structures meet their safety functional requirements it is necessary to establish that sound design concepts, rules, standards and methodologies in conjunction with proven design features have been used, and that the design is conservative with respect to its assessed capability. Guidance on the requirements for structural design is provided in P82 to P85, depending on the safety categorisation of the structure.

5) SAP P82 requires that the design should be conservative and follow appropriate national or international standards. In the case of gas-cooled reactor graphite cores there are currently no recognised national or international standards. As the core would normally be safety category 1 then best practicable conservative design and construction standards should be adopted (SAP P145). SAP P84 is particularly important for the core as there is no appropriate code or standard. Under these circumstances the design should be fully justified in the safety case or supporting design justification.

6) The safe working life of a graphite core and its components should be evaluated and defined at the design stage with particular emphasis on those components which are judged to be difficult or impracticable to replace. Adequate margins should be built into the design to allow for the effects of time dependent degradation (SAP P102).

7) All operational loadings and credible fault loadings should be identified and their magnitudes specified (P147). Load combinations should be defined. SAPs P119-122 cover external and internal hazard loads. Load definitions should be conservative, and remain appropriate for the proposed future operation of the structure. This is of particular importance when reviewing proposals for extended operation or for a change of use of structures or components.

8) The design should be supported by stress analyses, and if necessary model tests, to validate the methods used, to demonstrate that adequate margins against failure are maintained throughout the plant life (P165). Consideration should be given to the uncertainties associated with environmental loading when reliance is placed on out of reactor testing. Analyses and tests need to be done under a quality process that will provide a basis for relying on the results. The adequacy of margins to failure needs to be considered in the light of the perceived accuracy, reliability and conservatism of analysis and test results, their scatter and areas of uncertainty.

9) The design concept should incorporate appropriate protection systems and monitoring systems to enable the structure to be maintained within its safe operating envelope for the duration of the life of the installation. For core components, these would typically include: thermocouples for monitoring temperatures; leakage detection systems; inclusion of surveillance samples for monitoring of materials behaviour etc. Adequate arrangements need to be in place to ensure that these systems are maintained, inspected, and tested to ensure that the safety functional requirements continue to be met.

10) For existing plant it is recognised that the original design codes and standards may have changed, and other factors such as additional loads, degradation mechanisms, or advances in analysis methods may enhance, or erode, some of the unspecified safety margins inherent in codes. It should be established that the original design remains appropriate, or be demonstrated that any shortcomings are not significant in terms of the overall safety case. The assessment of the effects of internal and external hazards, for example those arising from dropped loads or earthquakes, may not have been addressed at the design stage for existing plants and needs to be carefully considered.

11) Safety submissions for existing plant should contain a comparison with present day standards and any significant deviation from modern design practice should be justified. Failure to meet modern standards should be identified by the licensee, and the implications addressed with the aim of showing that reasonably practicable improvements have been made, or will be addressed.

12) The design should take due account of degradation processes, including corrosion, erosion, radiation creep, fatigue and ageing, and for the effects of the chemical and physical environment. The potential for interaction effects should be considered, e.g. radiolytic oxidation and neutron damage. Due allowance should be made for uncertainties in the initial state of components and the rate of degradation. Of particular importance are degradation mechanisms for components that may be difficult or impractical to inspect in service. In this instance it is anticipated that conservative estimates would be included in the design and appropriate surveillance schemes specified. Monitoring and surveillance should be appropriate for the rate of progress of anticipated degradation mechanisms as well as giving more speculative coverage for unexpected degradation processes.

13) As there is no recognised design code or standard for graphite reactor cores the assessor should examine the justification provided by the licensee to establish that it was based on sound scientific understanding, and that the design methods were supported by suitable experimental verification and validation. Designs should be, or should have been, supported by appropriate research and development and any novel features adequately tested before coming into service, and subsequently monitored during service (P66).

4.10 Manufacture, Construction and Commissioning

- the application of high standards of manufacture, including in-process inspection, and construction, for the materials and processes used, SAPs Para. 201(d).

1) SAP P82 requires that the plant satisfy the best practicable standards of manufacture, construction, inspection and operation commensurate with the safety categorisation and reliability requirements of its component parts.

2) The material specification, manufacturing processes and inspections should be suitable and should be aimed at ensuring that the structure is as free from defects as

possible, and that the structure is tolerant of any remaining defects (P145 and P146). Components should be designed and fabricated to facilitate inspection during manufacture and during service.

3) To meet high standards of structural integrity it is necessary to establish that:

> (i) the manufacturing processes, process control, quality control, inspection, and testing are carried out in accordance with approved and qualified processes and procedures (P154 and P156).
>
> (ii) appropriate third party inspection of manufacture and inspection is specified to ensure that a high standard of workmanship has been achieved (P155, P156 and P157). Inspections of high integrity components should be redundant, diverse and qualified (qualification is the process previously referred to in the UK as validation). Pre-service inspections should be carried out at a late stage in the period prior to operation.

4) For graphite components (particularly graphite sleeves) the specification of a proof test before service provides some assurance that the as-built structure has been constructed to an adequate standard (P164). That is the material strength and section thicknesses are adequate. The reassurance may only be of limited value for existing plant where degradation mechanisms may have eroded any margins derived from the original proof tests and tests do not represent all loading conditions. Further proof tests in service are not usually feasible given the radiological consequences if failure occurred during such a test.

5) When dealing with existing plant it may not be possible to verify to the same extent as new plant that adequate standards of manufacture have been achieved. However, it should be possible to identify the manufacturer and to confirm that the manufacturer is, or was, a recognised company in the field. It may also be possible for the licensee to examine the manufacturing records still available, and reach some conclusions on the quality of manufacture. This could reveal strengths as well as weaknesses.

6) Care is required in accepting commonality arguments based on manufacture, operational experience or inspection of similar components. Broadly, commonality

arguments are strongest where highly correlated, common cause process deviations or degradation mechanisms dominate and weakest where process deviations and degradation mechanisms have a large random element.

7) For existing plant, part of the examination of the quality of original manufacture should include a review of manufacturing concessions to the original specification.

8) Pre-service inspection should be of sufficient extent to give adequate confidence that non-conformances will be detected before commissioning.

9) Commissioning procedures should be adopted which ensure initial and continuing quality and reliability of the core construction (SAP P98).

10) When considering modifications to existing plant, new components should be designed, manufactured, inspected and tested in accordance with modern standards and practice where appropriate. Any proposal that lowers the existing standard should not be accepted. This requires some judgement since we are dealing with what is reasonably practicable, and consistent with the overall system functionality.

11) The quality assurance and quality control system should be developed to ensure that non-conformities with manufacturing procedures, processes and specifications are identified. Where non-conformities are judged to have a deleterious effect on integrity, or significant defects are detected by in-process inspection, and remedial work is considered necessary, the remedial work should be carried out to an approved procedure and should be subject to the same design requirements as the original work (P157).

4.11 Component and Core Condition Assessment (CCCA)

1) Some graphite components may fail during the lifetime of current gas-cooled reactors. The distribution, mode and number of these failures need to be estimated to demonstrate that the cores will continue to perform their safety functions. Failures may occur due to: imposed loads from the restraint structure; internal stresses in graphite components or other external loads. The CCCA leg of a safety case should present the results of analyses to predict component and core condition. For an existing plant the CCCA leg may also incorporate the aspects of the design leg as discussed at Section 4.9.

2) Whilst this leg is similar to the core integrity leg of current safety cases there are significant differences and these are highlighted in subsequent paragraphs. The term "core integrity" has been dropped in this guide as it implies something that may not be the case when applied to a component but may be applicable to the core as a whole. However, core safety functionality may be affected before core integrity is affected.

3) The CCCA would normally be expected to be an independent leg of the safety case and is potentially therefore a strong argument. The assessor can expect the CCCA to predict graphite component and core condition at a defined stage in life and at the end of a defined operating period. At the start of life the design data and models may constitute the CCCA. The elements of this assessment are:

- i) Predictions of component materials properties and condition from an assessment of:
    - a) Neutron dose,
    - b) Radiolytic weight loss,
    - c) Irradiation and oxidation trend curves,
    - d) Stress analysis,
    - e) Condition assessment.
- ii) Prediction of core condition from an assessment of:
    - a) Component condition and interactions with other graphite core components and with other items such as fuel, control rods, core support structures, restraint structures, monitoring devices etc.,
    - b) Transients, faults and hazards.

4) The core condition assessment will need to make appropriate use of whole core, or partial core models, to adequately consider complex component-core interactions.
5) The CCCA may be deterministic with sensitivity studies or probabilistic. Ideally this should incorporate both approaches due to significant scatter in graphite data and uncertainties.
6) The CCCA should consider stochastic and systematic effects and in doing so will need to investigate the likelihood of damage clusters or damage cascades.
7) The CCCA need to consider all reasonably foreseeable potential component and core damage and failure mechanisms.
8) The key differences between a full and rigorous CCCA compared with the core integrity assessment leg of current safety cases are:

  i) Detailed knowledge of as-manufactured properties;

  ii) Detailed knowledge of how the cores were constructed;

  iii) Ideally the location of each brick, and associated properties should be known.

  iv) Fully validated methodology;

  v) Mechanistic understanding of materials behaviour and possible interaction of ageing mechanisms;

  vi) Validated component failure criteria;

  vii) Understanding of cracking behaviour;

  viii) Conservative or accurate predictions of component and core behaviour.

9) SAP P85 requires that due allowance should be made in the design for degradation processes and the effects of the environment. In the case of the core the following ageing processes need to be considered and the CCCA leg should accurately or conservatively model the individual effects and their potential interactions in predicting component and core condition and behaviour:
  i) Radiolytic oxidation due to gamma irradiation;
  ii) Effects of neutron damage;

iii) Irradiation creep;
iv) Sub-critical crack growth.

10) SAP P85 also requires that the design should allow for any uncertainties in determining the initial state of components and the rate of age-related degradation of components in the core environment. For a graphite core this is particularly important as the number of graphite components in a typical UK gas-cooled reactor is many thousands and, due to the nature of the graphite bulk production processes, significant variability in as-manufactured material properties may be expected. Reference 7 provides guidance on how to handle uncertainty and advises on precautions in the face of uncertainty.

11) SAP P87 considers the role of theoretical models employed in support of confirmation of the design or as a means of describing safety related conditions. For the CCCA leg many models are employed to predict component and core behaviour (such as: irradiation and oxidation trend models of materials behaviour; whole core models; etc). Any such models should be based upon a sufficient and sound scientific understanding and any necessary assumptions or approximations should demonstrably bias results in a safe direction (SAP P86). However, extreme care is cautioned where biased models or methodologies are used. Due to the complexity and complex interactions in predicting the behaviour of irradiated graphite components bias in one direction may result in conservative estimates for one mechanism or mode of component failure (and core damage) that might not be conservative for others. In some cases there may be assumptions that are conservative with respect to one mode of component failure but non-conservative with respect to another. Under such circumstances sensitivity studies may assist in identifying that conservative assumptions, and models adopted, are made for different modes of component failure.

12) SAP P88 requires that analytical models should be validated against experiments that replicate as close as possible the expected plant condition. Care is cautioned in interpretation and application of analytical models to anticipated plant conditions due to uncertainties. Where appropriate an independent check of results from an analytical model should be made using different methods or approaches to test model robustness.

13) Provision should be made to keep under review new data, scientific knowledge, research and operating experience to ensure that the safety case is not invalidated (SAP P89).

14) CCCA predictive models should be shown to be valid for the particular application and circumstances by reference to established physical data, experiment or other means (SAP P88). TAG 042 provides further guidance on validation. Where uncertainty exists in these data then appropriate safety margins should be demonstrated to account for this uncertainty. Extrapolation and interpolation from available data should be

undertaken with care and robust justification provided for data and model validity beyond the limits of current knowledge. For models of materials behaviour mechanistic understanding may be of particular value in increasing confidence where interpolation and extrapolation is necessary.

15) For components of particular concern and where it is not possible to confirm the ability to operate under the most onerous design conditions, reference data from commissioning or rig testing should be established for comparison against in-service test results (SAP P97).

Load analysis

- the analysis of all conditions within the design basis, SAPs Para. 201(b)

16) The safety case should include an analysis of the potential failure modes for all conditions arising from design basis loads. For those structures that are important for the safe operation of the installation, the safety case should contain identification of normal operating and potential fault conditions, including the effects of internal and external hazards.

17) The objective of the analysis is to demonstrate that the structures are capable of safely withstanding normal operating and fault loads for the projected life of the installation taking due account of potential degradation mechanisms.

18) For infrequent events the assessor may need to consider whether there is scope for alleviation of the most rigorous requirements for pessimism in the analysis. In such cases the safety case should provide a suitable justification for any relaxation. In terms of stress analyses, it may be reasonable to have stress limits that increase as the likelihood of the loading decreases. That is lower stress limits would apply to normal operating conditions, and higher stress limits to infrequent fault loading conditions.

19) For damage or deterioration mechanisms where the radiological consequences of failure are significant, the safety case should be supported by detailed analysis to demonstrate that the structure is capable of withstanding the identified normal operating and potential fault loads for the lifetime of the installation. The complexity of the analysis will be dependent on the safety categorisation of the component or structure. For the highest category this may include finite element stress analysis and procedures should be adequately verified and validated for the particular application as required by P165 - P168,

and that the limitations of the codes have been met. Model testing may be necessary to confirm the adequacy of the stress analysis.

20) The assessor should establish that data used in analysis is demonstrably conservative, and that appropriate studies are carried out to establish the sensitivity to the analysis parameters, particularly in relation to identification of any potential cliff-edge effects on the safety case.

21) Sensitivity studies (P167) to establish the effects of variations in the assessment parameters (including assumptions, data and methods) assist the engineering judgement of the overall safety case. Generally safety cases for components where the dominant failure mechanism is due to crack-like defects, should not rely entirely on integrity analyses. This is only one element of the case which could include consideration of conservative design, the use of known materials, original manufacturing quality and testing, materials investigations and inspections demonstrating no defect growth, and analysis to demonstrate defect tolerance at the end of life. The data used in any analysis should be demonstrably conservative. In particular, the uncertainties associated with material properties affected by degradation should be taken into account (P166).

22) The adequacy of margins against failure conditions, inspection capabilities, and integrity analysis should be considered in the context of the overall safety case rather than individual elements of the case. The assessor should apply engineering judgement to the various factors in reaching a conclusion on the adequacy of any particular case. The assessor should also take due note of precedents which have required the application of significant engineering judgement for the evaluation of the adequacy of safety arguments for high integrity components and structures.

23) Modern standards require consideration of fault loading conditions that may not have been addressed at the design stage for existing structures. In particular the effects on the integrity of the structure of internal and external hazards need to be addressed, P119 - P143. Some further guidance may be found in T/AST/013, on external hazards, and T/AST/014 on internal hazards.

24) Analysis of hazards posed by earthquakes present some difficulties particularly for existing structures.

Earthquake loading can be included in the design specification for new plant and analysed in the design substantiation. Existing structures may have been designed and constructed prior to seismic qualification being required, or may have been qualified to a less rigorous standard than that required for new structures.

25) The position is especially challenging for existing structures whose failure would give rise to unacceptable radiological consequences. P120 calls for demonstration that a structure is capable of withstanding earthquakes with a return period of no less than 10,000 years, (P120). The safety case should also show that there would not be a disproportionate increase in risk for an appropriate range of events that are more severe than the design basis event (P121).

26) This implies that components and structures whose failure is deemed to be incredible need to be shown to be capable of withstanding the loads associated with events whose frequency of occurrence is less than once in 10,000 years, unless it can be shown that the frequency of an event being exceeded is less than once in 10 million years (P119).

27) The safety cases for many existing structures include consideration of known, postulated or predicted component degradation. The assessor should ensure that due account has been taken of these effects in any seismic analysis of the structure and that appropriate acceptance criteria have been specified. It is important to ensure that the seismic safety case for the core is compatible with the overall safety case for the installation. In the case of some existing reactors, ALARP arguments may need to be assessed.

Materials

- the use of proven materials, SAPs Para. 201(c)

28) It is important to verify that safety significant structures are constructed from materials with well-established materials properties and behaviour (P154). The potential degradation mechanisms likely to be present should be established at the design stage and appropriate material chosen. Materials properties used in analyses should be demonstrably conservative e.g upper or lower bounds (dependent upon the property under consideration) of either generic databases or specific data that represent the component manufacturing and

fabrication conditions. It is important to ensure that failure mechanisms identified following a period of operation are adequately considered in a CCCA. If any unforeseen behaviour change or degradation mechanism is identified the licensee should review and if necessary update the relevant safety case.

4.12 Damage Tolerance Assessment (DTA)

1) The objective of the analysis is to demonstrate that the cores will be damage tolerant and retain their essential passive safety functions during normal operation and following reasonably foreseeable faults, for the projected life of the installation. This should take due account of potential degradation mechanisms.
2) The safe working life of a graphite core and its components should be evaluated. There should be an adequate margin between the intended operational life and the predicted safe working life of the core and its components (SAP P103).
3) The likely approaches for the DTA leg are essentially:

i) Use predictions from the CCCA analysis to establish if the core's passive safety functions are tolerant to the predicted damage. This has the disadvantage that the same assumptions, data and analysis underpins both the CCCA and the DTA. This is termed a dependent DTA.

ii) Assume a level of component and core damage to which core safety functions are demonstrated to be tolerant.

Or

iii) Establish the limit of component and core damage beyond which core safety functions are no longer tolerant. A safety margin would then need to be applied to this limiting condition (this may be in terms of time or degree of damage) and demonstrate that the core is always within this safe operating envelope.

4) From each of the above possible approaches examination, inspection, surveillance, sampling and test (EISST) programmes may be developed to track proximity to the assumed condition. Such an EISST programme should enable any limiting condition

to be detected using statistically significant sample sizes before conditions arise that may lead to the safety case assumptions or core safety functions being challenged. Where the DTA is unable to clearly demonstrate that safety functionality is achieved and demonstrated, under all reasonably foreseeable conditions then the licensee may resort to a consequences case. The assessor should establish whether the case presented is a damage tolerance case or where the core safety functions are not damage tolerant that the case presented has addressed the radiological consequences.

5) There should be a margin between the operating and fault envelope and any assumed condition over the full intended lifetime with due allowance for uncertainty. If component damage is shown, or assumed to occur, effects on core safety functions should be shown to be progressive, with the possibility of disruptive failures, without adequate forewarning, being remote and detectable. The DTA needs to consider local and global effects of component and core damage.

6) The assessor should establish that data used in the analysis is soundly based and demonstrably conservative, and that pertinent studies have established the sensitivity to the analysis parameters.

7) It should be shown that the core and its components can be operated and controlled within a safe operating envelope throughout its life. Following service exposure the cores must remain fit to perform their safety functions despite changes in geometry and the effects of identified degradation mechanisms. Parameters of the operating envelope should be consistent with the type of construction, potential modes of failure and operational considerations, SAP P160.

8) The DTA should demonstrate that the core is stable in normal operation and does not undergo sudden changes of condition when operating parameters go outside the specified range. The stress and strain limits for the core should ensure that the geometry will be adequately maintained to secure core and fuel cooling and minimization of the chance of core and fuel damage. The geometry of the core should be maintained within limits that enable passage of sufficient coolant to remove heat from all parts of the core. Where appropriate, means should be provided to reduce to a minimum the chance of any obstruction of the coolant flow that could lead to damage to the core as a result of overheating, SAP P264. As ageing and damage progress, in service changes to component and core condition and geometry might reduce, divert or impede coolant gas flow and thus reduce the effectiveness of cooling. The assessor should ensure that licensees have considered any mechanisms that might be significant and undertaken suitable and sufficient modelling of predicted or assumed conditions. Models of component, core and coolant behaviour should be adequately verified and

validated. The degree of rigour should be commensurate with the safety significance of any component and core damage.

9) Safe reactor shutdown and hold-down should not be inhibited by component and core damage under normal operation or fault conditions. The assessor should investigate with the fault studies assessor any damage mechanisms which may impede control rods and safe operation of any other shutdown or hold-down systems.

10) Graphite component and core damage should not lead to over-heated fuel causing failure of the primary coolant circuit or the fuel geometry being so changed as to affect adversely the heat transport process. Safeguards should be available to maintain the plant in a safe condition if this is not practicable, SAP P274.

11) Difficulties with removing fuel from fuel channels may occur as fuel distorts with irradiation. The fuel should still be able to be removed safely from the core despite any environmentally induced damage such as bowing or from other damage occurring in normal operation and in design basis fault conditions, SAP P273. Inability to remove fuel by normal methods would represent a major change in the operation of the reactor. If necessary, fuel retrieval could be linked to plans for Stage 1 decommissioning.

4.13 Analysis of consequences of core ageing on fuel and core cooling, shutdown, hold-down and fuel integrity

1) Where the DTA leg is unable to clearly demonstrate tolerance to component and core damage then the consequences for core safety functionality need to be assessed. This will need to include a consideration of the hazard, likelihood of affecting core safety functions and the consequences.

2) A consequences argument may sometimes be included as a secondary argument; that is although the DTA shows the core safety functions are tolerant to component and core damage there may be a residual uncertainty. To provide further assurance a consequences argument may be presented. However, where the consequences argument is the primary leg of the safety case, this leg assumes increased significance. The safety justification needs to assess the likelihood and consequences of component and core damage, for each damage mechanism, so that this information may be used in the fault studies to demonstrate the effectiveness of reactor protection or potentially by the PSA if the risk of fuel failure cannot be ruled out.

3) The consequences leg may be an independent, dependent or supportive leg. It is unlikely that a safety case could be made based on a consequences leg alone as it is unlikely that credible initiating event / fault frequencies could be generated especially where a consequences leg is being developed to address damage due to time dependent ageing. The analysis undertaken

needs to consider local and global damage, uncertainties and the resultant effects.

4) Faults and hazards which can give rise to consequential damage to components, systems and structures, such as depressurisation, need to be considered. If there is judged to be any evident risk of a number of channels being blocked simultaneously this is unlikely to be acceptable.

5) The graphite core assessment should consider the effect of the core on operability of the shutdown and hold-down systems. The assessor therefore needs to be familiar with these systems and aware of how graphite component and core condition may impact on their functionality.

6) Although secondary and tertiary shutdown systems may be provided, the control rods must be reliable as they are routinely used as the primary defence and also maintain control of reactor power generation. The assessor must be convinced that any interference between the control rods and the graphite will not prevent entry of sufficient control rods to execute their shutdown and long term hold-down safety functions or cause problems with the control of reactor power.

4.14 Monitoring

1) Monitoring in this context is defined as the gathering of information on plant condition or operating parameters by means of installed or other equipment or systems during plant operation.

2) The monitoring leg of a graphite core safety is potentially a fully independent leg and as a result therefore a strong leg. However, the assessor should take care in establishing whether the monitoring undertaken is a lead or lag indicator of component and core condition. If monitoring systems, processes and procedures result in safety function impairment before action is taken (or the process requires a response) then this would be a "lag" indicator. Alternatively if action is taken to remedy a situation before safety function impairment occurs then the monitoring is a "lead" indicator. Clearly the latter is a stronger argument as the former only allows a response after defence-in-depth is challenged. Monitoring is likely to be essential unless the CCCA clearly and demonstrably shows that no component and core damage occurs during operation. Even then some confirmatory monitoring would be expected.

3) SAP P76 and P268 outlines guidance on monitoring of safety related structures and components such as the reactor core. The core should be designed so that all safety-related conditions can be monitored to an adequate degree of accuracy. Monitoring of the core and its components may be undertaken during operation (either continuously or periodically) and during shutdown.

4) The scope and extent of monitoring should be commensurate with the required reliability. Where monitoring cannot be undertaken then measures should be taken to compensate for

the deficiency. Alternatively it should be demonstrated that adequate component and core performance will be achieved without such measures.
5) Where enhanced monitoring is introduced (over and above that previously undertaken), the safety case should consider measurements made in the past to ensure that any history is considered that may not have been previously correctly interpreted, ie previous trends need to be considered in developing criteria against which to assess future behaviour.

6) Monitoring should be performed at appropriate intervals, or continuously, to ensure that the results will enable timely identification of degradation. The assessor may also need to establish that the licensee has adequate arrangements for identifying suitable precursors to core safety functionality being affected; that suitable and sufficient criteria are available to warn of impending challenges; that reporting and acceptance criteria are developed; and that arrangements for the evaluation of monitoring results are adequate. Arrangements should be in place to secure timely response to mitigate untoward trends.

7) The design, manufacture, operation and maintenance of monitoring systems should be commensurate with the required duty and reliability. Systems should enable adequate trending of behaviour with time and the development of suitable and sufficient warning and investigation criteria. Any maintenance required to secure continued system functionality and reliability should be included in the maintenance schedule.

8) Monitoring may take the form of actual core safety functions such as freedom of control rod and fuel movements or surrogates. Results of monitoring should be trended, evaluated and reviews undertaken at appropriate intervals.

4.15 Examination, Inspection, Surveillance, Sampling and Test (EISST)

- pre-service and in-service inspection to detect defects at sizes below those which have the potential for causing or developing into a failure mode, and to size these defects conservatively, SAPs Para. 201(f)

1) Examination, inspection, surveillance, sampling and test in this context is defined as the gathering of information on plant condition or operating parameters by means of activities undertaken during a reactor shutdown such as a periodic shutdown.

2) For graphite cores, in-service examination and inspection are likely to form a significant element of the safety case, providing confirmation of their condition. Inspection provides an important element in establishing the integrity of structures and components that form a principal means of ensuring nuclear safety.

3) The EISST leg may be dependent, independent or informed from other legs and the results may be used to inform other legs. A dependent EISST leg is likely to be one where EISST is developed to confirm another leg of the safety case. An independent leg is where EISST are not developed from other legs of the safety case. An informed EISST leg is one where other legs of the safety case are used to inform the EISST programme, this is similar to a dependent leg but has a speculative element to it.

4) Due to the large number of channels and bricks present in a graphite-moderated gas-cooled reactor core it is likely to not be reasonably practicable to inspect a statistically significant sample size. This therefore implies that the chance of developing a statistically significant EISST plan that is independent of other legs is low. However, if high risk (likelihood / consequence) locations (selection being based on knowledge derived from other legs) are targeted for examination and inspection then statistically significant sample sizes may be reasonably practicable due to the smaller population of affected bricks. The assessor should bear the various options in mind when judging the adequacy of any EISST proposals and when seeking ALARP improvements.

5) The assessor should consider whether it is reasonably practicable to increase sample sizes where there is increasing uncertainty or weaknesses identified in the other legs of the safety case. Where EISST programme sampling plans are developed the strength of any proposals are likely to be increased where acceptance criteria and action, should acceptance criteria be exceeded, are included. Any such action may include further EISST, revision to the safety case etc.

6) The objectives of an EISST programme should be to demonstrate that: the core and its components are as defect free as possible and that the existence of defects can be established by inspection throughout the operational life (SAP P146); to confirm predicted materials properties changes; and detection of any unexpected safety related effects or trends.

7) The requirements for in-service examination, inspection, surveillance, sampling and testing, or other maintenance procedures, and frequencies for which specific claims are made in the safety case should be identified and included in the maintenance schedule (SAP P329).

8) Pre-service (PSI) and in-service inspection (ISI) procedures should be adopted which ensure that the initial condition of graphite components and core configuration, and any service

induced changes, may be reliably detected to secure safety case claims for component and core reliability (SAP P76 and P98). Such inspection should be of sufficient extent and frequency to give adequate confidence that degradation will be detected well in advance of any component damage developing into a degraded core condition and affecting core safety functionality.

9) Provision should be made to keep under review data arising from EISTT to ensure that the safety case is not invalidated (SAP P89).

10) The extent and periodicity of inspection should be commensurate with the operational duty, reliability and safety functional requirement (P76). Where defects, degradation or deviations from design intent are found in existing structures any proposed remedial action or technical justification should be assessed via the licensee's plant modification procedure, including Independent Nuclear Safety Assessment.

11) Inspection before and during service has three objectives:

> i) help confirm the plant is in the configuration assumed in the safety case;
>
> ii) help confirm any predicted degradation or ageing effect is developing at the anticipated rate:
>
> iii) help confirm there are no manufacturing shortfalls or in-service degradation processes other than those dealt with in the safety case.

12) It should be demonstrated that structures are inspected to the best practicable standards (part of P145), are as defect free as possible and are defect tolerant and that the existence of defects can be established by inspection throughout the operational life (P146).

13) In-service inspections should be carried out where they are reasonably practicable to enable the present condition of the structure to be confirmed, and to verify that the structure is behaving as the safety case assumes. In-service inspection provides a means of assuring that structures remain at all times fit for purpose (P162), and check for the unexpected. Difficulties may

arise in interpreting re-inspection results where modifications have been made to the inspection procedures following the original inspections.

14) Component and core inspection procedures and inspection personnel should be qualified for the defects of interest. The interpretation of inspection results and the assessment of their structural significance should be carried out by suitably qualified and experienced personnel (SAP P163). For crack-like defects, the defect sizes and orientation used in CCCA/DTA analyses should be pessimised, and include the contribution associated with the uncertainties in defect location and sizing for the particular inspection technique. The level of pessimism in the analysis will be dependent on the overall safety case and the consequences of failure.

15) Graphite component and core examination may take the form of visual inspection, photographic or video records, thickness measurements, or other forms of NDE, such that degradation of structures and components can be identified before core safety functionality is compromised.

16) Component and core condition assessments may be supported by periodic examination, inspection, surveillance, sampling and testing.

Materials monitoring

- the provision of in-service materials monitoring, SAPs Para. 201(g)

17) Provision should be made for periodic measurement of relevant properties, of fully representative materials and parameters, relevant to the design of the plant where such properties or parameters could change with time and affect safety (SAP P101). This may be achieved by sampling and testing of graphite components, and testing of pre-characterised samples inserted in suitable carriers (the latter may constitute a surveillance scheme).

18) The data derived from surveillance specimen materials may need to be examined in detail to ensure that the damage mechanisms are adequately understood and all relevant data have been included. The appropriate use of the data in any application should be justified in the safety submission, particularly when extrapolation of the data has been necessary. Extrapolation might be in time or exposure conditions. Any extrapolation or

correlation used to derive material properties should incorporate uncertainties, where applicable, and include the effects of different test rates on the results produced.

19) The adequacy of data derived from surveillance samples should be examined, as appropriate, to ensure as far as possible that the data accurately represents the component damage state, recognising the inherent scatter in any material properties estimation. The assessor should examine the safety case for these aspects and look for commitments for inspection and monitoring covering expected and unexpected phenomena (sometimes referred to respectively as 'safety case' based and 'speculative' inspections or monitoring).

20) Test data should adequately represent the materials and conditions of interest. Factors that may affect the validity of data are material specification, trace element content, porosity size and distribution, manufacturing processes and their control, temperature, environment, loading conditions and operational history. It may also be important to consider orientation of specimens with respect to the applied stress in the component.

21) Difficulties may arise for existing plants where particular loadings or degradation mechanisms may not have been identified at the design stage, or the understanding of the degradation mechanism changes. In these cases it is important that the licensee's safety case considers the likely material performance given the modified understanding, and establishes the implications for the performance of the structure. This may involve additional inspections, material sampling and testing, microstructural examination, testing of archive material, and simulation of material behaviour in order to improve confidence in the future performance of the structure. Evidence from similar plant experience elsewhere may be relevant. It may be necessary to monitor the structure to verify that the material is not deviating from the anticipated behaviour.

4.16 Ageing Management Programme

1) As the graphite core safety case is likely to be a life-limiting feature for some of the graphite-moderated gas-cooled reactors the assessor should consider whether it is appropriate for the licensee to have a core ageing management strategy in place to support continued operation (eg Refs. **4**, **5**, **6**). This is particularly important for Periodic Safety Reviews (PSRs) and

may also be applicable if previous PSRs have not adequately addressed this issue.

2) The Ageing Management Programme should draw out from the safety case the ageing management strategies and all of the associated commitments made to support the case, with timescales. This may then be used for monitoring completion of the commitments, including any changes to the safety case.

3) An effective ageing management programme for a graphite core should identify the strategy as to how core safety functionality will be achieved, demonstrated and maintained to the end of plant operating life, or to the end of the defined PSR period. This should include a consideration of:

> i) Operational experience.
>
> ii) A strategy and programme for examination, inspection, surveillance, sampling, testing and monitoring, through the PSR period, aimed at timely detection and characterisation of any degradation.
>
> iii) Review requirements and techniques for examination, inspection, surveillance, sampling, testing and monitoring to support continued operation and to demonstrate that ageing degradation is being adequately controlled.
>
> iv) Review the scope for making reasonably practicable improvements in examination, inspection, surveillance, sampling, testing and monitoring.
>
> v) Research requirements and research programme to support the safety case.
>
> vi) Review possible methods for mitigation of ageing which should include consideration of the scope for reasonably practicable plant modifications.
>
> vii) Consider the capability, to remove fuel from, and decommission a core with damaged components.

4.17 General advice

1) The assessor should examine, as appropriate for the key safety issues, the elements set out in paras 199 - 202 of the SAPs to the appropriate depth to establish whether the design, load analysis, materials, standards of manufacture, inspection and testing, quality assurance standards, protection systems, and provisions for material monitoring, maintenance and inspection provide the necessary confidence that the safety functional requirements will be met.

2) It should be emphasised that demonstration and achievement of core safety functionality relies to an extent on each of the legs outlined above. The assessor should apply engineering judgement to the overall safety case and for a multi-legged safety case each leg of the argument needs to be considered before coming to a view on the overall adequacy. Due consideration should be given to the potential for common mode failure mechanisms and factors which affect more than one leg of a multi-legged argument.

3) The assessor is not expected to repeat the analysis provided by the licensee, though sample checks may be appropriate. The assessment overall will be a sampling process. The assessor may wish to examine the licensee's process for developing the safety case to gain confidence in the content and claims of the safety case. The licensee's process for developing the safety case should include adequate checking, verification and independent review to a degree appropriate to the case (P315-P322, P71). This process relies on engineering judgement. This may be particularly demanding for existing structures where by comparison with modern standards, shortcomings may be present in some of the legs of the argument, and it may not be possible to introduce changes to the structure, see para 10 of the SAPs. Then other measures, such as changes to operating conditions, plant or procedural modifications, may be necessary to achieve an adequate safety case. In some cases, consideration should be given to the reasonable practicability of enhancing confidence in the safety case by additional research, inspections, measurements, material examination, analysis, or enhanced monitoring to detect potentially life-limiting deterioration in sufficient time to take appropriate remedial action or make alternative provisions to ensure safety.

4.18 Decommissioning

1) T/AST/026 provides guidance on designing plant to facilitate decommissioning. It also covers some factors that will need to be taken into account when plans are made to subject graphite reactor cores to "safestore" or dismantling.

2) Stored energy is most likely to be significant in the coolest zones of the oldest reactor cores. Neutron reflectors and other zones operated at relatively low temperatures such as in the UK's production and early research reactors will be of concern.

3) Neutron shields containing graphite together with boron may raise safety issues since boron is known to accelerate radiation damage in graphite.

4) Before stage 3 decommissioning starts, graphite samples will normally be taken and an assessment carried out to determine whether stored energy is significant and so that the ^{14}C and ^{3}H content can be properly taken into account in the waste management strategy.

5) The key safety functions of the graphite core should be maintained throughout the operating life of the reactor until it is de-fuelled. After all the fuel has been removed, less onerous demands may be placed on the graphite core and monitoring requirements can be revised accordingly. These are likely to include periodic visual inspection to confirm that the overall core geometry is being maintained and to establish the condition of individual graphite components.

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