ONR GUIDE			
CIVIL ENGINEERING CONTAINMENTS FOR REACTOR PLANTS			
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1. INTRODUCTION

1.1 ONR has established its Safety Assessment Principles (SAPs) [1] which apply to the assessment by ONR specialist inspectors of safety cases for nuclear facilities that may be operated by potential licensees, existing licensees, or other duty-holders. The principles presented in the SAPs are supported by a suite of guides to further assist ONR's inspectors in their technical assessment work in support of making regulatory judgements and decisions. This technical assessment guide is one of these guides.

2. PURPOSE AND SCOPE

2.1 The purpose of this technical assessment guide (TAG) is to provide assessors with guidance on the interpretation and application of ONR's Safety Assessment Principles for Nuclear Facilities 2014 (SAP) [1] that relate to civil engineering nuclear containments. For the purposes of this document, the term "containment" refers to reactor pressure vessels, reactor containment buildings, fuel stores, and waste stores that are provided to prevent the escape of nuclear matter to the environment under normal and fault conditions.

2.2 Further guidance on general aspects is available in the following interfacing TAGs [16]:

- NS-TAST-GD-013 External Hazards
- NS-TAST-GD-017 Civil Engineering
- NS-TAST-GD-014 Internal Hazards
- NS-TAST-GD-026 Decommissioning
- NS-TAST-GD-076 Construction Assurance

2.3 Civil engineering containments of interest fall broadly into three types:

- Pre-stressed concrete reactor pressure vessels (PCPV) where the concrete provides full support to a thin primary containment liner against reactor pressure and provides biological shield functions to the nuclear reactor core;
- Containment buildings that house (pressurised water or boiling water type) reactors and which are designed to contain leakage at pressure in the event of failure of the primary reactor pressure boundary;
- Containment structures which are not highly pressurised such as radioactive waste stores, vaults and silos, and fuel ponds containing nuclear material.

2.4 The components of a nuclear containment can also include isolating systems, penetrations, pipe work, and pressure relief valves that constitute the containment boundary however these items are not within the scope of this TAG.. Freestanding steel tanks and containers are outside the scope of this TAG, as they lie within the domain of ONR's Structural Integrity Specialism.

2.5 The safety and leak tightness of civil engineering nuclear containments depends on a correct assessment of the loadings likely to be applied to the containment and on the design of the containment structure to resist these loadings. Additionally it also depends on suitable in-service operational management arrangements to keep the containment within its designed service envelope and on adequate operational procedures being adopted for monitoring, inspection and testing throughout its service life.

2.6 This TAG notes the relevant SAPs [1], provides a commentary on these principles, identifies areas that assessors should consider when reviewing a safety case and lists relevant supporting references. Although this guide specifically addresses the sub-sections of the SAPs [1] concerned with containment, assessors are also referred to the SAPs that provide guidance on:

a. Key Engineering Principles;
b. Safety Categorisation;
c. Special Case Procedures;
d. Plant Ageing;
e. Reliability; and,
f. Structural Integrity.

2.7 This TAG contains guidance to advise and inform ONR inspectors in the exercise of their professional regulatory judgement. The guidance is intended for use in the assessment of both existing and new civil engineering containments of interest. Any comments on this guide, and suggestions for future revisions should be recorded on HOW2.

3. RELATIONSHIP TO LICENCE AND OTHER RELEVANT LEGISLATION

Licence conditions

3.1 The primary Licence Conditions [2] under which assessment of the design or integrity of containments and containment structures is carried out are:

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 15 (periodic review),
LC 17 (management systems),
LC 19 (construction or installation of new plant),
LC 20 (modification to design of plant under construction),
LC 22 (modification or experiment on existing plant),
LC 23 (operating rules),
LC 24 (operating instructions),
LC 25 (operational records),
LC 26 (control and supervision of operations),
LC 28 (examination, inspection, maintenance and testing)
LC 29 (duty to carry out tests, inspections and examinations),
LC 30 (periodic shutdown), and
LC 34 (leakage and escape of radioactive material and radioactive waste).
LC 35 (decommissioning)

Pressure system safety regulations

3.3 The Pressure Systems Safety Regulations (PSSR 2000) [17] require the owner or user of a pressure system to maintain and operate safe plant, to conduct regular examinations of the system and to keep suitable records. The primary purpose of the Regulations is to secure the safety of people at work i.e. to prevent serious injury from the hazard of stored energy as a result of failure of a pressure system or one of its component parts.

3.4 For the AGR and Magnox type concrete pressure vessels, EDF Energy -NGL and Magnox Ltd. respectively are the Competent Person (as defined in the Regulations) for the PCPVs. The Company Officer designated as the Appointed Examiner (APEX) for a particular PCPV undertakes the duties imposed by the Regulations on the Competent Person.

3.5 The Competent Person defined within the Regulations has two distinct functions. Firstly drawing up or certifying schemes of examination (Regulation 8) and secondly carrying out examinations under the scheme (Regulation 9). The Appointed Examiner's inspection regime including start-up statements and formal reporting on return to service after each periodic outage is undertaken and submitted in compliance with the reporting requirements of Regulation 9.

4. RELATIONSHIP TO SAPS, WENRA REFERENCE LEVELS AND IAEA SAFETY STANDARDS ADDRESSED

4.1 The principle SAPs [1] are referenced in Section 5 of this TAG and precede the most relevant paragraphs. The SAP [1] references are often relevant to other paragraphs.

4.2 The relevant WENRA Reference Levels [3] (Issue E, Design Basis Envelope for Existing Reactors and Issue F, Design Extension of Existing Reactors) both apply to existing reactors. This TAG generally includes the provisions of these Reference Levels and more detailed information can be obtained from [3].

4.3 For new nuclear power plants, due account should be taken of the requirements of the WENRA guidance on Safety of new NPP designs in [14] and [15].

4.4 The IAEA Safety Standard entitled "Safety of Nuclear Power Plants: Design" [4] has been considered in this review of this TAG and more detailed information can be obtained from this reference.

5. ADVICE TO INSPECTORS

5.1 **SAPs references precede the most relevant paragraphs of this TAG, however, the same SAP references are often also relevant to other paragraphs**.

Pre-stressed concrete pressure vessels: general

5.2 In this section the key elements which an assessor should consider in a safety case submission from a Licensee are identified for the most relevant SAPs [1]. The topics identified for consideration in the following paragraphs should not be considered as a check list but important areas which should be addressed when assessing a safety case. It is accepted there may be good reasons for a licensee not meeting a SAP [1]. In these cases, the assessor should ascertain the validity of the arguments presented. Since the SAPs [1] are not prescriptive, the assessor will need to judge the extent to which the safety submissions presented satisfy the principles. For many areas, this will rely on the skill and expertise of the assessor.

5.3 The various designs of the UK PCPVs have been able to withstand the test of time with only minor variations to the originally conceived safety cases. Under the Periodic Safety Review (PSR) process, the original designs have been assessed and confirmed using up to date finite element analysis techniques validated against original proof pressure test results and accounting for the operational time history loadings and instrumentation results. However, there remains a need for assessment criteria that can be applied at future PSRs and in assessing a vessel's suitability for return to service following Statutory Outage inspections, reactor fault excursions or the discovery of a defective or degraded strength component.

5.4 A detailed description of each PCPV pre-stressing system is given in Multi-Design Consultants' Report 'The Measurement of Tendon Loads in Pre-stressed Concrete Pressure Vessels and Containment Systems' [5]. The report gives a detailed historical account of each pre-stressing system including the design and development work leading up to initial stressing operations. There is also an examination of each system during its operational life as revealed by periodic anchorage load checking operations carried out under the site licence conditions up until February 2000.

5.5 British Standard 4975:1990 [19] specifies the design, construction, inspection and testing of PCPVs for nuclear reactors, including components that are necessary to maintain the structural integrity and leak tightness of the vessels. Whilst the design of the Magnox type PCPVs at Wylfa and Oldbury, as well as some of the earlier AGR type PCPVs, predate BS 4975, this standard remains in use as the prime standard for the structural assessment of the operational PCPVs.

5.6 The safety of a PCPV depends on a correct assessment of the loadings likely to be applied during its operational life and on the proper design of the PCPV to resist these loadings. Safety is then maintained by the application of defined procedures being adopted for operation of the reactor with adequate monitoring and inspection of the PCPVs during their service life being carried out. In assessing a PCPV's suitability for continued operation assessors therefore need to take into account the operating history of the reactor in respect of vessel temperature, CO_2 gas leakage, operating pressure and PVCW leakage as well as the findings from inspections where the effects of ageing may be apparent. Any significant proposed changes to operating parameters should be analysed and assessed against BS 4975 taking into account the current, aged, structural capability of the PCPV.

5.7 BS 4975 notes that "The structural integrity of a PCPV depends on the joint action of the concrete, the pre-stressing system, and bonded reinforcement if present. The ultimate load is reached when the structure reaches a condition at which it can no longer transmit the forces required for equilibrium". In existing designs of AGR and Magnox PCPV types, the ultimate load capacity is primarily dependent on the integrity of the pre-stressing system. When this system consists of a large number of tendons, the premature failure of a small number of these is unlikely to significantly reduce the strength of the PCPV. The capacity of the tendons for additional extension beyond that imposed by pre-stressing also provides assurance that the transition from elastic behaviour to the collapse mechanism is progressive.

5.8 Guidance is given below on the application of the SAPs [1] to the assessment of the results from periodic inspections under station Maintenance Schedule arrangements and the assessment of potential changes to PCPV safety cases due to changes in operating or fault conditions, and to ageing effects.

5.9 SAPs relevant to periodic measurement and inspection.

Engineering principles: ageing and degradation	**Periodic measurement of parameters**	**EAD.4**
Where parameters relevant to the design of plant could change with time and affect safety, provision should be made for their periodic measurement.		

Engineering principles: civil engineering: in-service inspection and testing	**Inspection and testing**	**ECE.20**
Provision should be made for inspection, testing and monitoring during normal operations		

aimed at demonstrating that the structure continues to meet its safety functional requirements. Due account should be taken of the periodicity of the activities.

5.8 To ensure the safe operation of PCPVs, ongoing assurance of its continued structural integrity is provided by the programme of inspections and measurements carried out by the Licensee's Appointed Examiner (APEX) and reported at each Statutory Outage. The scope of the examination is based on BS 4975 and is detailed in each Station's Maintenance Schedule, and normally covers:

- Condition of the accessible concrete surfaces of the vessel and support structure;
- Pre-stressing tendon anchorages;
- Tendon loads;
- Pre-stressing strand withdrawal, examination and tensile testing;
- Vessel settlement and tilt;
- Vibrating wire strain gauge monitoring;
- Vessel temperatures;
- Main reactor coolant loss;
- PCPV cooling water loss;
- PCPV top cap deflection;
- Review of operating history.

5.9 As a result of the above examinations and measurements the APEX prepares a report on the Statutory Outage inspections and is usually able to make a recommendation that the PCPV is fit for a further specified period of service. In reviewing the APEX's Report the assessor should be satisfied that all the Maintenance Schedule requirements have been addressed, that any recommendations from previous APEX reports have been implemented and that the conclusions drawn are consistent with the findings from the inspections and measurements. If not all the previous recommendations can be closed out before the next start-up, it is important that they have been reviewed and fitness for purpose safety arguments made to justify start-up with the recommendation still outstanding.

5.10 The passage of time and the consequent relaxation of tension in the pre-stressing tendons results in a diminishing margin of pre-stress above the originally specified Minimum Design Load (MDL). The MDL, a value used in the design process, is taken to be the tendon anchor load which should be exceeded by the arithmetic mean of all the residual tendon anchor loads in the PCPV. The use of the arithmetic mean value in the design process is considered acceptable where the relative stiffness of the tendon system and the concrete mass render minor variations in tendon load unimportant.

5.11 Residual tendon anchor loads are periodically measured by testing at least a 1% sample of the tendons on each PCPV and the mean value of each periodic sample is calculated for each PCPV. Often top and bottom tendon anchorage loads are considered separately and in the case of AGRs with helically wound tendons, the mean effective anchorage load at the top and bottom anchorages should both equal or exceed the MDL. . The periodic test sample does not provide the true arithmetic mean of the population of tendon anchorage loads, it provides an estimate of it. The inaccuracy in the estimate will be insignificant to the assessment where the variance of the test load data is small, and where the margin between the MDL and the arithmetic mean of the test loads (as estimated by the sample) is large. Where the variance is large and the margin is small, the test data should be considered at an appropriate confidence level. An appropriate confidence level will depend on the consequences of the MDL being breached, for each PCPV.

5.12 It should also be considered that the MDL is not a specified design safety limit in BS 4975. The limiting design condition is the compressive stress in the vessel concrete, and the relationship between the MDL and the compressive stress is calculated by computer analysis. Whilst a large margin exists between the estimated mean tendon load and the MDL for a PCPV it is convenient and sufficient to use the MDL as a benchmark to demonstrate the presence of an adequate safety margin. At some sites this margin is becoming relatively small and might, in the near future, reduce to zero. This would not necessarily mean that the PCPV has inadequate safety margins, rather that the safety case for continued operation should be made on the basis of the computer analysis and the calculated compressive stress in the concrete.

5.13 When assessing safety margins, consideration should be given to any uncertainty as to the condition of the tendon strands and the effectiveness of the corrosion protection grease applied to the tendons at the construction stage. This is particularly important where a tendon has been subsequently wetted by pressure vessel cooling water (PVCW) leakage or subjected to combined PVCW and CO_2 leakage. In addition, whilst the periodic inspection of a sample of tendons gives some reassurance of their integrity, it must be remembered that there will always be a proportion of tendons that may never be inspected due to access difficulties or obstructions that are too costly in time to remove.

5.14 Generally, where operating environments that were not anticipated when the periodic measurement regimes were devised, are currently known or suspected to have occurred, the measurement regimes should be amended to suit. For example, where tendons are known to have been wetted by PVCW leakage, the sampling regimes should be extended and targeted to all known and suspected areas of wetting and known wetted tendons should be considered for replacement.

5.15 On PCPVs where the location and arrangement of tendon anchors facilitates safe access to test, inspect and if necessary replace suspected damaged or wetted tendons, it should be expected that these tendons are replaced promptly as a matter of routine.

5.16 On PCPVs that must be taken out of service to facilitate safe access to the tendons, pre-outage inspections of tendon anchors in known and potentially wetted areas of the PCPV should be undertaken to inform the location and scope of detailed inspections and tendon strand replacements to be undertaken during each outage. Laboratory examinations of a sample of damaged tendon strands along with their protective grease layer should be undertaken to identify the cause of the damage. There is an expectation that the causes of tendon damage and of the degradation of their protective grease layer should be clearly understood and that wetted strands are replaced before return to service of the PCPV. Where this expectation is not met, the potential consequences should be fully understood and a programme of further mitigation prepared on an ALARP basis.

5.17 SAPs relevant to functional performance and Loading.

Engineering principles: civil engineering	**Functional performance**	**ECE.1**
The required safety functional performance of the civil engineering structures under normal operating and fault conditions should be specified.		

Engineering principles: civil engineering: design	Loadings	ECE.6
Load development and a schedule of load combinations, together with their frequencies, should be used as the basis for structural design. Loadings during normal operating, testing, design basis fault condition and accident conditions should be included.		

5.18 For the operational PCPVs the main concern is any change to the extant normal operating or claimed fault loading conditions that may be introduced to take account of potential changes in the safety case of other reactor components. For example, the potential for increased reactor over-pressure due to an increased likelihood of boiler tube or boiler spine failure; or increased over-pressure due to an increased risk of clogging of safety relief valves due to debris in the main reactor coolant. Similarly, the concrete temperatures expected during normal operation or fault conditions may be increased due to a revised safety case for undetected blockage or leakage of the PCPV cooling systems (PVCS). Operational temperatures in the PCPV may also gradually rise due to deterioration of the vessel internal insulation; most likely in the upper parts. All these examples may effectively result in changes to the safety functional performance requirement of the existing civil engineering structure of the PCPV. The assessor should therefore be aware that apparently unrelated safety case revisions may have a combined effect on the PCPV safety case and should establish that the Licensee has fully taken this into account in his revised safety case, i.e. that the required safety functional performance of the civil engineering structure should be fully understood and specified.

5.19 SAP relevant to independent arguments.

Engineering principles: civil engineering	Independent arguments	ECE.2
For structures requiring the highest levels of reliability, multiple independent and diverse arguments should be provided in the safety case.		

5.20 Where changes to a reactor component safety case may impose increased demands on the existing PCPV safety case the structural integrity of the vessel should be reassessed and shown by the Licensee to meet the requirements of SAP paragraphs 337 and 338 and to establish what safety margins exist.

5.21 If a reduction in the MDL is proposed as part of a revised safety case the assessor shall establish that an adequate safety margin remains bearing in mind the aged condition of the reactor vessel strength components, the potential for future ageing and the inherent uncertainty in the knowledge of the actual aged condition of some of the pre-stressing tendons.

5.22 It should be borne in mind that most of the AGR type PCPVs were designed to allow for the future return to the original design condition by re-stressing of the pre-stressing tendons and the Licensee’s arguments as to why the original MDL should not be restored by this means should be established by the assessor. Regardless of the justification provided for a reduced MDL it must be recognised that adoption of a reduced MDL automatically gives a real reduction in the safety margin which must be considered together with any other long term ageing effects which may also reduce margins.

5.23 Gradual long term increases in the ambient concrete temperature of the upper half of the vessel are apparent in some PCPVs such that the average tendon load measured at the PCPV Top Cap is markedly lower than the average measured at the Bottom Cap. Where this is the case the prevailing tendon anchor loads should be considered separately in the top anchorages and the bottom anchorages for comparison of each against the MDL.

5.24 SAPs relevant to structural analysis for safety case changes. Where changes to an extant safety cases are supported by structural analysis or model testing this should meet the requirements of SAP Engineering Principles ECE.1, ECE.12, ECE.13, ECE.14 and ECE.15 with respect to the demonstration that the PCPV can fulfil its safety functional requirement over the lifetime of the facility based upon analysis which meets these ECE requirements as to the use of data, sensitivity studies and validation methods.

5.25 A number of finite element analyses have been carried out for the PCPVs to establish the effect on safety function of various types of faults or defects. For example the effect of failure of groups of pre-stressing tendons; of asymmetric loss of tendon load; and of general loss of tendon load. These analyses give some understanding of the behaviour of the vessel in the event of unexpected findings at periodic inspections and are an aid to judgement for the assessor but specific case by case justifications should be requested from the Licensee. When assessing a defect specific safety case the assessor should bear in mind the accumulated body of defects justified in previous defect specific safety cases. Where new finite element analysis is presented to justify a reduction in the pre-stressing MDL due to age related tendon relaxation it remains arguable whether the associated reduction in safety margin should be considered acceptable when the means are available to restore the original design margins by re-shimming. Re-shimming involves re-tensioning the tendons and re-installing the anchors, and it should be noted that given the large number of tendons in a typical PCPV such an exercise would be a major undertaking. As noted above, by definition, a reduced MDL results in a reduced safety margin during both normal operation and during fault conditions.

5.26 SAPs relevant to defects and ageing.

Engineering principles: civil engineering	**Defects**	**ECE.3**
It should be demonstrated that safety-related structures are sufficiently free of defects so that their safety functions are not compromised, that identified defects can be tolerated, and that the existence of defects that could compromise safety function can be established through their life-cycle.		

Engineering principles: ageing and degradation	**Lifetime margins**	**EAD.2**
Adequate margins should exist throughout the life of a facility to allow for the effects of materials ageing and degradation processes on structures, systems and components.		

5.27 Where periodic outage inspections find the existence of defects in replaceable components of the pre-stressing system the default expectation should be that the component be replaced. Where defects are due to a common cause, for example, due to wetting from PVCW leakage resulting in corrosion of pre-stressing tendons, the assessor should request the removal of sufficient adjacent tendon strands for inspection and testing such as to establish to full extent of the potential defectiveness.

The assessor should also have an expectation that the Licensee should seal the leak sources causing the corrosion problem to prevent further degradation.

5.28 It has been found that even some newly replaced tendons have been severely corroded after a relatively short period in a wetted environment, [6 & 22]. Therefore in instances where leak sealing is found to be ineffective, tendons known to be subjected to wetting (along with adjacent tendons that could also be affected) should be scheduled for interim inspection between outages with particular attention being paid to the condition of their grease protection.

5.29 Defects such as cracks in the visible external concrete face of the vessel are subject to long term monitoring by the PCPV APEX. Gradual but permanent increases in concrete temperature due to changed ventilation or minor variations in operating conditions may cause increased concrete cracking due to drying shrinkage. In the event that significant changes in crack width or extent of cracking are found, or if new cracks are found, the assessor should be satisfied that the cause of the changes is understood and that potential adverse trends in crack development are acceptable for the next operating period.

Pre-stressed concrete pressure vessels: pressure vessel cooling systems

5.30 The AGR type PCPVs are generally provided with two 100% duty PVCS cooling circuits of unlined small bore steel pipe work either attached to the back of the vessel liner or feeding penetration cooling jackets. In some instances the two PCPV Top Cap cooling circuits may not be truly independent of each other but have some interdependence. The objective of the PVCS is to keep concrete temperatures within prescribed limits and therefore to limit the development of adverse temperature gradients within the concrete and around penetrations. During periods of prolonged reactor shutdown the PVCS is used to circulate heated water around the vessel to maintain concrete temperatures within the specified range.

5.31 To prevent corrosion of the internal surfaces of the PVCS pipe work the PVCW is demineralised, de-aerated and dosed with lithium hydroxide to achieve a pH of around 10 to 10.5. Notwithstanding these measures, leaks from the PVCS into pre-stressing tendon ducts are relatively common with the potential for corrosion of wetted pre-stressing tendons. At Hartlepool power station the phenomenon of minor CO_2 pressurisation of some PVCW circuit legs has also been noted. This is due to ingress from a CO_2 leak site adjacent to a PVCW pipe leak site.

5.32 Each PCPV has a safety case for partial or full loss of PVCS which invokes the use of the Low Pressure Back-Up Cooling System, a once through flow arrangement which can provide a limited amount and duration of cooling. Safety cases are also in place for total loss of cooling with and without natural circulation of the primary CO_2 gas coolant and for longer term post event cooling whereby in some situations elevated concrete temperatures may be maintained during depressurisation to prevent concrete cracking.

5.33 The Heysham 2, Torness and Hunterston B PCPVs have all been affected at various times by minor blockages of parts of the PVCS with the potential for increased concrete and penetration temperatures. Blockages have been caused by small sized debris in the system becoming trapped at the throttled back flow control valves. The potential exists for coincident blockage of both the 100% duty dual A and B circuits leading to elevated concrete temperatures and unacceptable thermal gradients.

5.34 There is the potential for loss of PCPV penetration restraint with subsequent penetration ejection or of failure due to elevated temperature of the penetrations and surrounding concrete known to be 'non-tolerant' to elevated temperature. Some extant safety cases for loss of PVCS require periodic flow measurements. At Statutory Outages (and at other periods required by the safety case) the assessor should ensure that any reductions in flow identified by flow checking are within the requirements of an extant safety case or that plant adjustments have been carried out to restore flows and where necessary, flow filtering is taking place at these sites to remove the cause of the blockages.

Pre-stressed concrete pressure vessels: vibrating wire strain gauges

5.35 During construction, vibrating wire strain gauges (VWSG) were installed at key positions within the concrete of each PCPV to monitor the performance of the PCPV during the proof pressure test. A full set of instrumentation generally being provided on the lead PCPV at each station with a reduced set installed on the second PCPV. This instrumentation is not a requirement of the long term safety case but continues to be electronically monitored by the stations, reviewed by APEX and reported to ONR at each Statutory Outage for each PCPV.

5.36 With the passage of time a proportion of the VWSGs have ceased to function or now give erratic results. However overall trends in compressive strain are still apparent and as such the instruments still give good evidence of PCPV performance. For some PCPVs, work has been carried out to compare the results of time history finite element analysis of PCPV behaviour, from proof pressure test onward, to the recorded strain variations with a good degree of correlation being found. The VWSG results show the long term trend in PCPV performance and give an indication of the development of zones of low compressive or small tensile stresses as the pre-stressing relaxes with time. The assessor should maintain ONR's expectation of the Licensee that the strain gauge results continue to be collected, assessed by the APEX (including comparison with available finite element analysis results) and reported to ONR.

5.37 During the Boiler Closure Unit (BCU) recovery project at Heysham1 and Hartlepool power stations, it was found that it was possible to re-activate and re-baseline some of the VWSGs within the BCU concrete previously thought to have failed completely. It has therefore become possible to re-activate presently 'failed' VWSGs within the body of the PCPV concrete should this become necessary in the future. More recently, the use of modern data loggers has increased the number of active gauges at some stations.

Pre-stressed concrete pressure vessels: with "pod type" boilers

5.38 The PCPVs at Hartlepool and Heysham 1 Power stations include "pod type" boilers within the thickness of the walls of the PCPVs. These preclude the installation of helical pre-stressing tendons within the walls and compressive pre-stress is provided via layers of tensioned steel wire wrapped around the external cylindrical surface of the PCPV, and vertical pre-stress tendons within the walls around the boilers.

5.39 Routine inspection indicated corrosion damage to the tensioned steel wire at a number of locations around the external cylindrical surface of the PCPV and a major intrusive investigation was conducted. The outcome is recorded in four reports by the licensee. The outcome has influenced future inspection requirements.

5.40 The Boiler Closure Units (BCUs) within the PCPVs at Hartlepool and Heysham 1 Power stations have a concrete infill within a steel shell and contain the boiler inlet and outlet pipe work. They are also maintained in a state of compressive pre-stress by means of layers of tensioned steel wire wrapped around the external cylindrical surface in a wire winding chamber. The original safety case was based upon the believed presence of a benign corrosion environment within the BCU wire winding chambers such that there was no degradation in the pre-stressing wires. However inspections of the anchorages and windings enclosure found the presence of water and identified a number of instances of broken wire due to corrosion failure, corroded and thinned wires and instances of anchor slippage.

5.41 In 2008 through 2009 a revised safety case based upon the modification of fitting lightly tensioned pre-stress lock-in bands over the top of the existing pre-stressing wire windings was prepared by the Licensee. This modification was accepted by ONR on the basis that there was sufficient confidence in the existing levels of pre-stress, due to the property of frictional restraint within the wire winding bundle, such that even with a number of wire breaks the pre-stress level within the concrete would be maintained. The modification included the installation of a dewatering system to each BCU, a humidity controlled nitrogen environment and instrumentation to monitor the level of tension in the pre-stressing lock-in bands. The revised safety case specifies constant monitoring of the wire winding environment and of the tension in the lock-in bands with phased inspection over Statutory Outages of the wire winding anchorages and lock in bands. The Licensee monitors the long-term condition of the BCUs, and adherence to the revised safety case, by means of the BCU Oversight Panel.

5.42 Because further PVCW leaks into some wire winding chambers have occurred since the modification was carried out the assessor should ensure that the choice of and number of BCU enclosures chosen for inspection at Statutory Outages adequately reflects the likelihood of further corrosion degradation at each BCU. It should be noted that the Licensee's choice of BCUs for Statutory Outage inspections has a tendency to be dictated by the programme for PCPV penetration weld inspections, the timing of which may not be compatible with the requirement for BCU winding chamber inspection as indicated by the monitoring results from the previous operational period. Where excursions from the safety case have occurred, such as failure of the controlled environment in the winding chamber, the assessor shall seek confirmation that the controlled environment has been re-established in the shortest possible time and that any further degradation that may have occurred remains within the safety case envelope.

5.43 The Licensee's safety case for the modifications recognised that the BCU could no longer be claimed as an Incredibility Of Failure (IoF) component but that the fitting of an external steel restraint (ESR) to prevent ejection of the central section of the BCU concrete, brought the BCU back into the 'tolerable if ALARP' range. ONR recognises but do not use the term IoF but accepts that the ESR provides a secondary restraint system in the event of partial pre-stressing failure. The ESR is composed of frameworks of heavy cross section steel members bolted to the main BCU holding down studs and framed around the steam, feed and super-heater penetrations that pass through the BCU. To give a partial forewarning of failure of the BCU, the compressive strain in key members of the ESR is monitored during reactor operation.

5.44 A disadvantage of the ESR is that at periodic outages, where inspection of the penetration welds or of the BCU wire windings is required, the ESR must be completely dismantled and removed before inspections can take place. Since the ESR is fabricated to tight tolerances and the load bearing feet in contact with the BCU concrete are fitted with shims to guarantee load transfer under BCU failure conditions, (and to avoid the ESR loading the BCU during normal operation), the dismantling and re-installation of the ESR requires careful control. The assessor should establish that adequate checks have been carried out post re-installation to confirm that the ESR has been correctly reassembled to effectively fulfil its safety function.

5.45 The Licensee's safety case for the modifications recognised that the additional BCU condition monitoring required to meet the safety case would require oversight and instituted the BCU Oversight Panel (BOP). The work of the BOP is available for review by ONR and provides a forum for Hartlepool and Heysham 1 Power stations to discuss monitoring record data with the Licensee's Central Technical Organisation.

Containment buildings which contain reactors: general

5.46 Reactor containment buildings have several safety functions. Under normal operating conditions the containment building provides support to the reactor vessel, primary circuit and associated plant. However, during fault and accident conditions which may result in reactor primary circuit leakage when the interior of the building becomes pressurised the function is to contain any escaped coolant and reactor core inventory against escape to the outside environment.

5.47 Reactor containment buildings may be constructed from reinforced concrete, pre-stressed concrete or steel plate and may act in combination with reactor building external envelopes to protect the reactor pressure vessel and associated safety systems from external hazards (including aircraft impact), to provide some biological shield functions, to provide containment and to provide a degree of security from unauthorised access.

5.48 SAPs that relate to containment buildings.

Engineering principles: containment and ventilation: containment design	**Minimisation of releases**	**ECV.2**
Containment and associated systems should be designed to minimise radioactive releases to the environment in normal operation, fault and accident conditions.		

Engineering principles: containment and ventilation: containment design	**Means of confinement**	**ECV.3**
The primary means of confining radioactive substance should be by the provision of passive sealed containment systems and intrinsic safety features, in preference to the use of active dynamic systems and components.		

5.49 In assessing the basic design parameters chosen by the designer for the structural analysis of a containment building the assessor should ensure that there is not an undue dependence for structural stability on the effectiveness of active pressure reduction systems in the determination of the peak internal design pressure and temperature. In the UK it has been the design practice to ensure the containment structure remains essentially within the elastic range during the most likely fault and accident conditions.

5.50 PWR type containment buildings should have a secondary containment that should be able to withstand the possible pressurisation of the volume between the primary and secondary containments in the event of an accident or a malfunction of the interstitial annulus ventilation system, and should be able to withstand external loads either alone or in combination with the primary containment. The secondary containments of other reactor types may be provided by reactor building external envelopes.

5.51 SAPs that relate to structural performance.

Engineering principles: civil	**Functional performance**	**ECE.1**

engineering		
The required safety functions and structural performance of the civil engineering structures under normal operating and fault conditions should be specified.		

Engineering principles: civil engineering	**Independent arguments**	**ECE.2**
For structures requiring the highest levels of reliability, multiple independent and diverse arguments should be provided in the safety case.		

5.52 Parargraph 337 of the SAPs requires that the containment design be based upon the use of sound design concepts and proven design features. Specific nuclear design standards should be used as appropriate, where such standards exist.

5.53 The assessor should establish that a detailed schedule of loading for both serviceability and ultimate limit states, covering normal operation, plant transients, faults and internal and external hazards has been prepared and that the design analysis covers potential failure modes for conditions arising from design basis faults and potential in-service degradation mechanisms.

5.54 The assessor should be satisfied that sufficiently high safety margins are provided to ensure that for structure types that are inherently less ductile, failure would be extremely unlikely to occur for credible initiating events. Failure modes for severe loadings should be predictable, gradual and detectable in advance.

5.55 The assessor should establish that only proven materials are used for construction and that high standards are applied, as verified by inspection of the construction work and of the materials used.

5.56 To support assessment of the design the assessor may seek evidence of design substantiation by alternative calculation and analysis routes. In this respect the provision by the Licensee of Third Party endorsement of the design by means of independent analysis can provide the assessor with a high level of confidence in the design. Similarly, for assurance of construction compliance with specification and quality on site, the assessor may also seek endorsement of the construction process by a Third Party that is independent of the site specific management and quality assurance arrangements.

5.57 It is worthy of note that the only existing UK reactor containment building, at Sizewell B power station, was subject to the requirement that it be 'licensable in the country of origin'. To meet this requirement the structural integrity of the containment building had to be certified by the UK equivalent of an American 'Authorised Nuclear Inspector'. This was done by setting up an independent inspection agency function within the Client organisation to monitor the construction of the containment building and to carry out an independent analysis of the containment building design. Both design and construction were then able to be certified to American standards.

5.58 SAPs that relate to relevant codes and standards.

Engineering principles: safety classification and standards	**Standards**	**ECS.3**
Structures, systems and components that are important to safety should be designed, manufactured, constructed, installed, commissioned, quality assured, maintained, tested and inspected to the appropriate standards.		

Engineering principles: safety classification and standards	Codes and standards	ECS.4
Where there are no appropriate established codes or standards, an approach derived from existing codes or standards for similar equipment, in applications with similar safety significance, should be adopted.		

5.59 The current (2018) UK nuclear new build programme will use a variety of designs for the reactor containment buildings. Some of these designs will have been subject to regulatory approval within the country of origin but the newer designs may still be the subject of an ongoing approval process. In considering a new containment building design the assessor should establish the design standards and loading schedules on which the design is based and their degree of equivalence or otherwise to UK standards and Eurocodes. The assessor should also establish the degree of regulatory scrutiny that the design has undergone in the country of origin and whether there are any shortfalls or gaps in this assessment. A judgement can then be made as to where and how much further scrutiny should be applied.

5.60 SAPs that relate to the design basis.

Engineering principles: civil engineering: design	Loadings	ECE.6
Load development and a schedule of load combinations,, together with their frequencies, should be used as the basis for structural design. Loadings during normal operating, testing, design basis fault and accident conditions should be included.		

5.61 Primary containment. The pressures and temperatures that apply within the primary containment under normal operating, fault, and accident conditions should be determined and validated. The safety function and safety categorisation of each part of the structure, plant and equipment that forms the containment boundary to contain any nuclear matter arising should also be clearly delineated. The ultimate limit state design requirements for the containment boundary will depend on the chosen combinations of loading. For example, a loss of coolant accident (LOCA) may be considered coincident with an earthquake loading if it is deemed credible that an earthquake may induce, or occur at the same time as, a LOCA. Also for example, for the EPR type containment building design, a load case combining rupture of the reactor pressuriser surge line, a LOCA and the design earthquake, results in a maximum containment pressure of 0.48 MPa absolute combined with a design base earthquake (DBE) 0.25g pffga. Additionally, for an EPR type containment building severe accident with core melt, and including the loads due to local hydrogen deflagrations, the requirement is to demonstrate by calculation that the internal containment remains leak-tight at a maximum pressure of 0.65 MPa absolute, and a maximum temperature of 170 °C.

5.62 Primary containment. The peak fault pressures and temperatures seen by some types of containment building during a LOCA may be dependent on the reliability of containment emergency internal spray or heat removal systems activated to relieve or reduce peak pressure. The assessor should therefore establish that there is a consistent and validated set of arguments supporting the choice of design and extreme load combinations to which the containment must be designed. The forces on the containment induced by the activation of passive and/or active pressure and temperature reduction measures should be fully understood and quantified.

5.63 Secondary containment. The secondary (outer) containment should be designed to withstand external loadings of human or natural origin. Serviceability should be demonstrated for loadings due to meteorological phenomena (snow, wind, extreme temperatures, etc) and for the 'inspection' earthquake. Serviceability must be ensured for the DBE and for loadings corresponding to aircraft impact or an external explosion. To prevent releases of radioactivity in accident situations, the outer containment design should be sufficiently leak-tight to enable a negative pressure to be maintained in the containment annulus without the operation of the annulus ventilation system for a specified grace period. The outer containment must also be able locally to withstand the effects of a high-energy pipe break.

5.64 SAPs that relate to structural analysis.

Engineering principles: civil engineering: structural analysis and model testing	**Structural analysis and model testing**	**ECE.12**
Structural analysis or model testing should be carried out to support the design and should demonstrate that the structure can fulfil its safety functional requirements over the lifetime of the facility.		

Engineering principles: civil engineering: structural analysis and model testing	**Use of data**	**ECE.13**
The data used in any analysis should be such that the analysis is demonstrably conservative.		

Engineering principles: civil engineering: structural analysis and model testing	**Sensitivity studies**	**ECE.14**
Studies should be carried out to determine the sensitivity of analytical results to the assumptions made, the data used, and the methods of calculation.		

Engineering principles: civil engineering: structural analysis and model testing	**Validation of methods**	**ECE.15**
Where analyses have been carried out on civil structures to derive static and dynamic structural loadings for the design, the methods used should be adequately validated and the data verified.		

5.65 The structural performance of a new containment building should be demonstrated to be conservative by a combination of analysis; design, model test and pressure test of the completed containment. The design should generally meet the requirements of SAP paragraphs 337 to 339 to establish what safety margins exist.

5.66 Regardless of the work done by other regulators where an 'overseas' containment building design is employed, the assessor should be satisfied that appropriate load combinations have been used; that sufficient numerical analysis has been carried out to demonstrate that the structure will meet the requirements of the SAPs; and that the computer codes used for design have been validated and the outputs verified. Validation of the computer codes used may be against model testing and/or against alternative computer codes. Validation may need to consider the limits of application of the calculation method, the structural representation in the model, comparison with other calculation methods, the level of quality assurance and user proficiency. The material properties used in the analysis shall also be shown to be validated by test.

5.67 In considering the design of a containment building it must be confirmed that all the component parts of the containment boundary have been identified: e.g. all structures which form part of the boundary, isolating systems, access penetrations, pipe work and cable penetrations. The safety functions of each element under normal, fault, and accident conditions should be defined together with appropriate criteria to measure their ability to fulfil these functions under the specified load combinations. In this respect the assessor should give particular attention to local membrane strains around large penetration groups, plant access hatches and personnel airlocks to establish that they remain within code allowables.

5.68 Calculations of beyond design basis conditions may involve the prediction of extreme physical behaviour and the calculation methods used are often not amenable to rigorous validation. In such cases the results should be reviewed to ensure that they sensibly reflect the expected physical performance in broad terms.

5.69 The assessment should also consider whether the design has demonstrated that the containment building's ability to meet its safety functional requirements is not impaired by the effects of internal and external hazards. Additionally SAP paragraph 525 Clauses a) to n) set out the general design requirements for any form of nuclear containment in the broadest sense. The requirement to establish a set of design safety limits and to define the performance requirements in the event of a severe accident including requirements for structural integrity and stability also apply in most part to containment buildings.

5.70 SAPs that relate to construction issues.

Engineering principles: safety classification and standards	**Standards**	**ECS.3**
Structures, systems and components that are important to safety should be designed, manufactured, constructed, installed, commissioned, quality assured, maintained, tested and inspected to the appropriate codes and standards.		

Engineering principles: civil engineering	**Defects**	**ECE.3**
It should be demonstrated that safety-related structures are sufficiently free of defects so that their safety functions are not compromised, that identified defects can be tolerated, and that the existence of defects that could compromise safety functions can be established through their life-cycle.		

Engineering principles: civil engineering: construction	**Materials**	**ECE.16**
Civil construction materials should comply with the design methodologies employed, and be shown to be suitable for the purpose of enabling the design to be constructed and then operated, inspected and maintained throughout the life of the facility.		

Engineering principles: civil engineering: construction	**Prevention of defects**	**ECE.17**
The construction should use appropriate materials, proven techniques and a quality management system to minimise defects that might affect the required integrity of structures.		

Engineering principles: civil engineering: construction	Inspection during construction	ECE.18
Provision should be made for inspection during construction to demonstrate that the required standard of workmanship has been achieved.		

Engineering principles: civil engineering: construction	Non-conformities	ECE.19
Where construction non-conformities or identified defects are judged to have a detrimental effect on integrity, remedial measures should be applied to ensure the original design intent is still achieved.		

5.71 During the contemporary (2014) round of containment building constructions in France, Finland and China a number of construction problems have come to light which if not properly addressed could lead to shortfalls in safety functional performance during operation. OECD NEA Report, [Ref. 7] analyses construction experience events at Flamanville 3, Olkiluoto-3 and Shin-Kori 1 and reports on the lessons learned from these events and proposes regulatory actions to aid in the prevention of safety events in the operating phase. The assessor should be aware of current containment design and construction issues to ensure that these have been adequately addressed in the containment that is the subject of assessment.

5.72 In addition to the usual routine inspection of construction work carried out by the Licensee's 'Site Resident Engineer' function it is also desirable to have additional Third Party inspection of the containment building construction, and some Third Party testing of construction materials independent of the pressures of the site management function.

5.73 In the USA the construction of a containment building has to be certified by an 'Authorised Nuclear Inspector', [Ref. 8 & Ref.9], There is also a requirement for the design of the containment building to be independently certified. For the construction of the UK's first Pressurised Water Reactor (PWR) containment building an arrangement equivalent to the American Authorised Nuclear Inspector, known as the Independent Inspection Agency was set up and effectively carried out these functions. ONR's expectation is that similar inspection arrangements will be established for construction of each new containment building.

5.74 The assessor should review the arrangements for categorising and sentencing non-conformances and be satisfied that sentencing is carried out at a design management level appropriate to the safety significance of the non-conformance.

5.75 Concrete. A number of reports are available detailing base slab and containment wall concreting problems where concrete cracking has occurred. To avoid problems with heat of hydration cracking, and the consequent need for remedial works to be agreed by the Regulator, the assessor should ensure that the Licensee carries out adequate concrete mix trials using the aggregates, cement, cement replacement, placing equipment and methods to be used for construction. Where it is proposed to pour a thick containment base slab in two or more layers the assessor should be satisfied that sufficient additional reinforcement is provided to ensure that the layers act monolithically.

5.76 Concrete. Following concrete mix trials the assessor should establish that an evaluation of the properties of the hardened concrete that are relevant to the behaviour of the primary containment has been carried out and the results are compatible with the values used in the containment building design and analysis. An evaluation of the following properties would be expected:

a) compressive strength
b) tensile strength
c) modulus of elasticity
d) poisson's ratio
e) creep
f) shrinkage
g) coefficient of thermal expansion
h) coefficient of thermal conductivity.

Where possible, the properties shall be determined under test conditions conforming to those expected in the containment building under design, fault, and accident conditions.

5.77 Concrete. When the difficulties of placing and compacting concrete at a congested location may affect the resulting concrete properties or the behaviour of the containment structure under loading, appropriate concreting trials shall be carried out under conditions and configurations simulating the actual structure. Concreting trials may be appropriate to simulate the dome/ring beam and wall/base junctions and other highly reinforced areas. Further guidance is available in Ref. 12.

5.78 Primary Containment liner. The primary containment steel liner forms an impermeable and air tight membrane to the inner faces of the containment building concrete and is usually secured to the concrete by means of steel studs and steel channel sections. It also acts as an inner shutter when the concrete is poured. The floor of the liner is usually covered by several metres of mass concrete. At support points for plant and equipment and around access hatches and penetrations the liner thickness is increased locally. The transition from thin to thick steel plate is accommodated by tapered thickness plates, to avoid a stress-raising step-change in liner thickness.

5.79 Primary containment liner. Where a vented containment building is proposed and the maximum containment design pressure and temperature have been reduced by virtue of the ability to vent to atmosphere via a filter system the assessor should ensure that the containment has the structural capacity to accept the full unvented pressure albeit that the structure may go into the inelastic range. This provides a safeguard against the possible blockage of filters and the consequent need for unfiltered venting and provides resilience against more severe accident conditions.

5.80 Primary containment liner. Due to its relatively small stiffness the liner's behaviour will be dictated almost entirely by the behaviour of the concrete structure. Strains and stresses will be induced in the liner by deformation of the concrete structure, along with stresses from restrained thermal expansion of the liner. Liner stresses are therefore strain controlled. Thus, gross cracking of the concrete or extensive overheating of the liner accompanied by high strain cycles would have to occur before any serious damage to the liner could develop.

5.81 Primary containment liner. The assessor should establish that the design of the steel liner, liner plate welds, embedded retention components and thickness transition plates is such that differential strain rates that will arise in fault conditions and at elevated temperature are accommodated without tearing or bowing of the liner. It should also be established that the liner will not tear in the event of the stud anchors failing first.

5.82 Primary containment liner. Before construction of the liner begins the assessor shall ascertain that a design justification of the specified construction tolerances with respect to local alignment, bowing, dishing and ovality is in place to ensure that no unaccounted for strains are accumulated due to construction errors. Where erection of the liner will be significantly in advance of concreting a temporary wind brace structure may be required to control construction strains and ensure stability.

5.83 Primary containment liner. Where the liner is buried in concrete the assessor should establish that adequate means of pressure testing buried welds are provided such that it can be confirmed that these welds remain pressure tight after the possible disturbance due to concrete placing. Where novel forms of design are used such as use of steel-concrete composite units or a 'floating liner base' it should be established by calculation to appropriate codes, mock up testing and post concreting pressure testing that the liner meets its safety functional requirements.

5.84 Primary containment liner. The assessor should establish that liner weld procedures, welder qualification, weld materials and the welding environment are all appropriate to the nuclear safety classification of the liner both for on-site and off-site fabrication.

5.85 Pre-stressing system. In most containment building designs the ultimate load capacity is primarily dependent on the integrity of the pre-stressing system. However, compared to the multitude of tendons provided in AGR and Magnox type PCPVs, a PWR type containment building contains a relatively small number of tendons, the premature failure of which may not be readily apparent or detectable if the tendons are grouted in place.

5.86 Pre-stressing system. The assessors expectation should be that the pre-stressing system be designed such that for all but the most extreme accident load cases the containment structure remains generally within the elastic range and has some degree of redundancy even at infrequent fault load conditions. The design should be robust to the undetected failure of several tendons, either together or distributed throughout the structure, such that their loss will not significantly reduce the vessel's ability to meet safety functional requirements. For design basis load conditions the assessor should ascertain that there are no 'cliff edge effects' that result in structural instability in the event of a small further increase in loading. Some assurance is provided by the design capacity of the tendons for additional extension beyond that imposed by pre-stressing. This ensures that the transition from elastic behaviour to the collapse mechanism is progressive.

5.87 Pre-stressing system. The assessor should establish that the values of modulus of elasticity and the stress/strain relationship of pre-stressing tendons to be used in the design have been evaluated by testing full-scale tendons of suitable length. This length should be sufficient to ensure a uniform loading of each of the bars, wires or strands forming the tendon.

5.88 SAPs that relate to pre-stressing system reliability and inspection.

Engineering principles: civil engineering: design	**Inspectability**	**ECE.8**
Designs should allow key load bearing elements to be inspected and, where necessary, maintained.		

Engineering principles: maintenance, inspection and testing	**Reliability claims**	**EMT.6**

> Provision should be made for testing, maintaining, monitoring and inspecting structures, systems and components (including portable equipment) in service or at intervals throughout their life commensurate with the reliability required of each item.

5.89 The required inspections and their scope, frequency and acceptance may be based on the requirements of ASME Section XI (Ref.18) (or equivalent code) and include examination of the containment building and pre-stressing system, and containment leakage rate testing. Inspections occur over 10 year 'intervals', with refuelling outages occurring every 18 months.

5.90 Un-bonded tendons. In UK practice it has been the norm to install un-bonded tendons firstly in the Magnox and then in AGR type PCPVs, and latterly in the Sizewell B PWR containment building such that it is possible to check the load in any tendon and, if necessary, re-tension it. Additionally, it is also possible to remove tendons for examination to assess their continuing integrity and, if necessary, to replace them in the event that corrosion or other defect is found. This facility gives continuing assurance of the serviceability of containment buildings (and PCPVs) throughout their lives via a series of periodic checks (Statutory Examinations).

5.91 Bonded tendons. Whilst pressure testing a containment building with bonded tendons via a programme of integrated leak rate testing provides proof of overall structural integrity there is little assurance of tendon integrity to be gained in the interim periods between tests. Therefore where it is proposed to use bonded tendons the assessor should establish that a fully effective means of in-service monitoring of tendon behaviour is provided to give assurance of the tendons' continuing integrity throughout service life. The monitoring arrangements provided should be capable of giving a near equivalent level of in-service integrity assurance as would be obtained by the use of un-grouted tendons. The effectiveness of the long term monitoring instrumentation should be proven and validated as part of the pre-operational structural over-pressure test.

5.92 Bonded tendons. The long term structural integrity of a fully grouted (bonded) tendon is dependent on the completeness and quality of the grout body around the tendon within the tendon duct. The assessor should therefore be satisfied that the installation and grouting procedures have been fully tested to establish that the site construction methods will result in a fully contiguous grout body fully adhered to the tendon and duct. The effectiveness of the grouting method should be demonstrated at full scale using the actual grout material to be used in the structure.

5.93 Dome ring beam. One particularly difficult area of containment design and construction occurs where the torispherical containment dome is connected to the cylindrical containment 'skirt' by means of a ring beam which may contain both vertical and horizontal pre-stressing and anchorages as well as bonded reinforcement. The assessor should be satisfied that sufficient trials have taken place to demonstrate that this complex junction can be properly constructed under site conditions without the inclusion of voids or poorly compacted areas in the concrete.

5.94 Polar crane support. The support brackets for the polar crane girder beam are generally attached to the cylindrical section of the containment wall either on a concrete corbel inboard of the steel liner and attached by shear key and pre-stressing bars or by direct pre-stressed connection to the steel liner/concrete cylindrical wall. In either case the liner plate is penetrated by pre-stressing and reinforcement bars and the leak tightness of the liner must be assured under normal loading and at fault pressurised loading and temperature. The assessor should be satisfied that sufficient analysis has been carried out to demonstrate that the containment will remain essentially leak tight under all design load and temperature combinations.

5.95 SAP that relates to the over-pressure test.

Engineering principles: civil engineering: in-service inspection and testing	Proof pressure tests	ECE.21
Pre-stressed concrete pressure vessels and containment structures should be subjected to a proof pressure test, which may be repeated during the life of the facility.		

5.96 On completion of construction an initial proof pressure test is carried out in order to demonstrate the elastic behaviour, strength and the leak tightness of the containment building. The objective of the test is to verify that the containment building can withstand the applied pressure with no visible damage; has acceptable maximum concrete crack width at peak pressure; develops strains and deformations compatible with design calculations; and provides verification, after completion of the test, of the reversibility of deformations, (i.e. elastic behaviour).

5.97 The test only partly represents Loss Of Coolant Accident (LOCA) accident conditions as it is performed by air pressure at ambient temperature. The outward thrust on the concrete resulting from thermal effects on the steel liner is not represented and this therefore justifies use of an over-pressure for the test. It is accepted international practice that containments with a steel liner are tested to 1.15 Pa where Pa is the peak over-pressure during a LOCA. Double containments without a steel liner are tested to 1.00 Pa. [Ref. 10].

5.98 The limiting allowable volumes of leakage during a pre-operational leakage test should be set in accordance with international standards at the time of testing. Reference 10 gives an acceptance level for total leakage rate in percentage of contained air per 24 hours of 0.75 x 0.1% for a PWR and 0.75 x 0.5% for a BWR.

5.99 For the EPR the maximum leak rate from the inner containment is set at 0.3%/day based on the mass of gas contained in the volume bounded by the inner containment at a pressure of 0.55 MPa absolute.

5.100 The requirement for a structural over-pressure test is quite onerous in terms of the resources required to pressurise the containment, and in terms of the safety of site personnel. With the provision of suitable instrumentation there is however much information to be gained on the performance of the structure but this must be balanced against the potential for local damage, cracking or weakening of the structure if the test is not carefully controlled. Pressure raising should be in discrete stages with pressure held at each stage for a period of time at each stage before the stage pressure is reduced slightly to allow personnel access to the external face of the structure for examination before progression to the next pressure stage.

5.101 It should be noted that undertaking a repeat pressure test at an operational site poses specific problems as any confined volume within the pressurised containment will experience the applied test pressure. Plant, equipment and instrumentation must therefore be adequately prepared (usually by removing them or venting them to the containment air).

Unpressurised containments: general

5.102 Virtually all power stations have some form of spent fuel storage associated with reactor operations. Two technologies have been developed for storage. Initially the storage method was wet but in recent decades dry storage techniques of varying types have been developed. Both wet and dry storage technologies have to address the following requirements:

a) Fuel cladding integrity should be maintained during handling and exposure to the corrosive effects of the storage environment

b) Fuel degradation during storage should be prevented through providing adequate cooling in order not to exceed fuel temperature limits

c) Sub-criticality of the spent fuel is to be maintained under normal and accidental conditions

d) Radiological shielding of the spent fuel should protect plant operators, the public and the environment from receiving radiation doses in excess of regulatory limits

e) Environmental protection should be assured by minimising the release of radioisotopes

f) Fuel retrievability must always be available

5.103 Some dry storage facilities may be required to stay operational well beyond the life of the power plant (up to 50 or 100 years). In this section guidance is given on the assessment of both fuel pond and dry store containment structures.

Unpressurised containments: fuel storage ponds

5.104 Fuel storage ponds are usually built in reinforced concrete with the structure built above ground or at least at ground elevation. Some early ponds were open to the atmosphere, but operational experience and the need to control pond water purity has resulted in new storage ponds being covered. The reinforced concrete structure of the pond, including the covering building, is generally expected to be seismically qualified. Most ponds are stainless steel lined, some are coated with epoxy resin based paint and older ponds may be unlined. ONR expect that new ponds will be constructed to modern standards and will be lined with stainless steel.

5.105 The ponds are normally filled with deionised water or dosed with chemical additives depending on the type of fuel to be stored and the adopted method of treatment. Some ponds are filled with boronated water (with a low ph) to increase shielding and this introduces a significant potential for corrosion of the reinforcement of the concrete structure in the event of leaks or chronic seepage of the contained water. The water is either a fixed quantity or a once through pond purge. Water activity levels are maintained as low as reasonably achievable (ALARA) by either in-pond or external ion exchange systems or by limiting activity release to the bulk pool water. ONR expect leakage from the pond should to be minor and should be monitored, either by means of an integrated leakage collection system or via the inter-space in pools with two walls. In all new pond designs and construction the water leakage should be collected and returned to the main pond.

5.106 In addition to the control of activity by ion exchange or purge, some ponds are operated with an imposed chemical regime. This is for pH control, maintaining boron levels for criticality control where necessary, and the maintenance of acceptably low levels of aggressive anions such as chloride and sulphate to minimise fuel degradation. Maintenance of good water chemistry provides good water clarity and usually prevents the occurrence of micro-biological organisms. If these do occur, they are treated with specific chemical dosing.

5.107 SAP that relates to the assessment of new fuel ponds.

Engineering principles: key principles	Defence in depth	EKP.3
Nuclear facilities should be designed and operated so that defence in depth against potentially significant faults or failures is achieved by the provision of multiple independent barriers to fault progression.		

5.108 By definition, a fuel storage pond structure plays a principal role in ensuring nuclear safety, by storing nuclear fuel, e.g. containment, shielding and cooling. For a new-build concrete fuel pond it is ONR's expectation that the pond will have two independent watertight linings, each provided with leak detection system with alarm facilities. The leak tightness of each of the two linings should be demonstrated by test during construction. It should also be provided with a high capacity water make-up and cooling systems in order to provide the required level of defence in depth against significant faults or failures.

5.109 Different structural design considerations may also apply dependent on whether the pond is within an aircraft protected shell or outside it. Outside of the protected envelope there may be an additional requirement for the pond structure to withstand externally-generated hazards such as aircraft impact. Complete or partial protection from aircraft impact of the isolation valves of some systems may also be required.

5.110 Design and construction of a fuel pond should also generally meet the requirements of the Civil Engineering SAPs (ECE.1 to ECE.24), the External Hazard SAPs (EHA.1 to EHA.19) and the Containment and Ventilation SAPs (ECV.1 to ECV.10).

5.111 The reinforced concrete of the ponds should be designed to appropriate water retaining codes and standards and the design should accommodate thermal expansions due to elevated pond water temperatures without unacceptable levels of leakage. The pond should be seismically designed and have sufficient freeboard to accommodate seismic sloshing. Water bars should be positioned such that they will not be subject to deterioration due to radiation or shall be qualified against such effects. Leak collection/detector channels should be provided at concrete construction joints, and behind major liner welds.

5.112 Primary pond wall and base thicknesses should be sufficient to provide adequate biological shielding to allow man entry into the inter-space between the primary pond walls/base and all parts of the double containment structure.

5.113 The pool secondary containment structure should be designed to the same standards as the primary structure and be designed to accommodate water depth equal to pond design water level.

5.114 SAP that relates to new fuel pond testing.

Engineering principles: maintenance, inspection and testing	Type-testing	EMT.3
Structures, systems and components should be type tested before they are installed to conditions equal to, at least, the most onerous for which they are designed.		

5.115 During construction, the leak-tightness of each of the two independent watertight linings should be demonstrated by tests. For metal linings, "vac-box" tests and radiographic inspection of all joints and components is appropriate. For chemical product based coatings (linings), proprietary testing of the completed lining is appropriate. On completion of construction of the pond, a water test should be carried out over a set period of time to demonstrate the water tightness of the completed pond structure and there should be no loss of water other than by evaporation. Where shielding and containment is provided by the unlined reinforced concrete of the pond structure, e.g. above-liner base slabs and above-ground pond walls where any leakage is contained by gravity flow to the linings below, the test should be carried out after sufficient soak time to allow for water absorption by the concrete. For stainless steel lined ponds that are not normally emptied, the liner should be subject to an additional requirement of 100% radiographic inspection.

5.116 Where for radiological purposes it is necessary to ensure the containment function of the storage pond and over-building as a whole there may be a requirement to determine a maximum static air leakage rate from the building with the ventilation systems out of service. This leakage rate may typically be set at a value of half of the building volume per day.

Unpressurised containments: dry fuel stores

5.117 In a dry fuel storage facility the used fuel elements are typically stored within gas-tight storage containers, either horizontally or vertically supported, within a naturally ventilated reinforced concrete building that provides some shielding. An alternative arrangement used at Sizewell B site and proposed for Hinkley Point C utilises a light streel-framed building where shielding is provided by thick jackets of steel and concrete construction that surround each individual fuel container. The storage containers are usually cooled by natural convection. The cooling air gradually warms and moves upwardly and transfers the heat to the outside environment. In this type of store primary containment of the fuel is by means of the gas tight containers. The building structure provides the safety functional requirements of support to maintain the fuel containers within a constant position and air-path; protects the containers against external hazards; maintains a dry environment and gives a degree of biological shielding. The storage building also supports the remote fuel handling facilities such that the fuel is always accessible and removable.

5.118 Design and construction of a dry fuel store should also generally meet the requirements of the Civil Engineering SAPs (ECE.1 to ECE.24), the External Hazard SAPs (EHA.1 to EHA.19) and the Containment and Ventilation SAPs (ECV.1 to ECV.10).

Unpressurised containments: high and intermediate level waste stores

5.119 The design and construction requirements for waste stores are generally in accordance with those for dry fuel stores above but may be with the additional requirement for a containment ventilation system to maintain the store at a negative pressure relative to atmospheric pressure.

5.120 In waste stores where the shielding fully encloses the gas-tight container, it is usually claimed as a further containment barrier.

5.121 Design and construction of a waste store should also generally meet the requirements of the Civil Engineering SAPs (ECE.1 to ECE.24), the External Hazard SAPs (EHA.1 to EHA.19) and the Containment and Ventilation SAPs (ECV.1 to ECV.10)

Other containment types

5.122 Various other forms of containment structure exist at UK sites which include vaults, silos and buffer stores:

5.123 Vaults are subterranean reinforced concrete structures (usually single-skinned and unlined) that have been used at Magnox sites to store various radioactive items (for example parts of Magnox clad stripped from used fuel, non-fuel sections of fuel stringers, or in-reactor instrumentation stringers). Cooling is not provided, but containment and shielding is. These legacy structures are generally being emptied and the material re-packaged and moved to above-ground storage facilities. Such vaults often suffer from ground water and/or rain water ingress, which can effect their structural integrity as well as the condition of the contents.

5.124 Silos are usually cylindrical reinforced concrete containments that sit above ground (often within other structures). They are sometimes used to store activated resins that have been used in fuel pond water conditioning or reactor coolant gas-by-pass filtering plant. They are un-cooled, single-skinned and usually dry.

5.125 Buffer-stores are cooled, lined storage areas that exist within the walls of a PCPV, around the periphery of the reactor core. They are used to temporarily store new or used reactor fuel stringers or in-vessel instrumentation stringers. The PCPV provides the shielding and liner support.

5.126 The general assessment principles described in the preceding sections apply also to these containment types, but as each of these structures has different challenges to their ability to provide containment, the assessor should adjust their attention to consider the specific risk or challenge that each specific containment type experiences.

Generic external and internal hazards

5.127 SAPs that relate to external and internal hazards

Engineering principles: external and internal hazards	**Earthquakes**	**EHA.9**
The seismology and geology of the area around the site and the geology of the site should be evaluated to derive a design basis earthquake (DBE).		

Engineering principles: external and internal hazards	**Extreme weather**	**EHA.11**
Facilities should be shown to withstand weather conditions that meet the design basis event criteria. Weather conditions beyond the design basis that have a potential to lead to a severe accident should also be analysed.		

Engineering principles: external and internal hazards	**Flooding**	**EHA.12**
Facilities should be shown be to withstand flooding conditions up to and including the design basis event. Severe accidents involving flooding should also be analysed.		

5.128 The structures should be designed to withstand the design basis event criteria for extreme environmental conditions including flooding. The event criteria chosen should reflect the likelihood that a national permanent long term storage facility may not be available for many decades and the local store may by default become a permanent long term store.

5.129 Whilst the provision of a very long term dry environment does not require the use of advanced engineering there have nevertheless been a number of instances of water penetration into fuel storage buildings resulting in fuel damage or compromising the fuel handling route. Water ingress has been found to be due to poor detailing at roof/wall interfaces and to poor or no maintenance of rainwater gutters and pipes due to inaccessibility or to no planned inspection and maintenance.

5.130 The assessor should therefore pay particular attention to the design and detailing and the materials specified for the roof water-proofing. The design should ensure that water collection gutters and down pipes are readily to view and easily inspected. The roofing and drainage materials used should have a proven and demonstrable longevity. Where new or novel materials applications are proposed they should be of certified longevity if necessary by accelerated ageing tests. Before fuel loading, the water tightness of the building and roof drainage pipe work should be demonstrated by testing. If practicable, provision should also be made for in service testing if this can be achieved without putting the dryness of the storage areas at risk.

6. REFERENCES

Ref. 1 Safety Assessment Principles for Nuclear Facilities. 2014 Edition Revision 0. ONR Document (Trim 2014/443919)..

Ref. 2 Licence Condition handbook. ONR. February 20170

Ref.3 Western European Nuclear Regulators' Association (WENRA). Reactor Harmonization Working Group (RHWG). WENRA Reactor Reference Safety Levels for Existing Reactors. WENRA. January 2014.

Ref. 4 IAEA Safety Standard. Safety of Nuclear Power Plants: Design. Site Specific Safety Requirement SSR-2/1.

Re. 5 IMC Report - 'The Measurement of Tendon Loads in Pre-stressed Concrete Pressure Vessels and Containment Systems', Multi-Design Consultants, February 2000

Ref. 6 ONR Visit Report (Trim - 2009/102216) **-** Oldbury Periodic Outage 2009

Ref. 7 NEA/CNRA/R (2012)2 – Nuclear Energy Agency, Committee on Nuclear Regulatory Activities, First Construction Experience Synthesis Report 2008-2011, Working Group on the Regulation of New Reactors (WGRNR), 03-May-2012.

Ref. 8 ASME Section III, *Nuclear Power Plant Components*, ASME QAI-1, paragraph 3-3, *Qualification for Authorized* Nuclear Inspector Concrete (C)

Ref. 9 The American National Board of Boiler and Pressure Vessel Inspectors, NB-263, *Rules for Commissioned Inspectors*

Ref. 10 US NRC Regulations, Title 10 Code of Regulations,10CFR 50 Appendix J, Primary Reactor Containment Leakage Testing for Water Cooled Power Reactors.

Ref. 11 IAEA Safety Standards Series, Site Evaluation for Nuclear Installations, Safety Requirements, NS-R-3.

Ref. 12The Royal Academy of Engineering: Engineering the Future- Nuclear Construction Lessons Learned Guidance on Best Practice: Concrete, 2012. ISBN: 1-903496-81-0

Ref. 13 IAEA-TECDOC-1025 Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: Concrete Containment Buildings, 1998

Ref. 14 WENRA Statement on Safety objectives for new nuclear power plants WENRA November 2010

Ref. 15 RHWG Report on Safety of new NPP designs WENRA March 2013
http://www.wenra.org/

Ref.16 ONR Technical Assessment Guides.

NS-TAST-GD-013 External Hazards
NS-TAST-GD-017 Civil Engineering
NS-TAST-GD-014 Internal Hazards
NS-TAST-GD-026 Decommissioning
NS-TAST-GD-076 Construction Assurance

Ref.17 Pressure Systems Safety Regulations (PSSR 2000) Approved Code of Practice and Guidance ISBN 978 0 7176 6644 7.

Ref.18 ASME BPVC-XI-2017 ASME Boiler and Pressure Vessel Code, Section XI: Rules for Inservice Inspection of Nuclear Power Plant Components

Ref.19 British Standard BS4975:1990. British Standard Specification for Prestressed concrete pressure vessels for nuclear engineering. British Standards Institution.

7. GLOSSARY AND ABBREVIATIONS

ABWR	Advanced Boiling Water Reactor
AGR	Advanced Gas-cooled Reactor
ALARA	As Low As Reasonably Achievable
ALARP	As Low As Reasonably Practicable
APEX	Appointed Examiner
BCU	Boiler Closure Unit
BOP	BCU Oversight Panel
BSO	Basic Safety Objective
BWR	Boiling Water Reactor
DBE	Design Basis Earthquake
EPR	Evolutionary Pressurised (Water) Reactor
ESR	External Steel Restraint (BCU)
IAEA	International Atomic Energy Agency
LOCA	Loss Of Coolant Accident
Magnox	Magnesium Non-oxidising (fuel)
MDL	Minimum Design Load
PCPV	Pre-stressed Concrete Pressure Vessel
pffga	peak free field ground acceleration
PSR	Periodic Safety Review
PSSR	Pressure Systems Safety Regulations (2000)
PVCS	Pressure Vessel Cooling System
PVCW	Pressure Vessel Cooling Water
PWR	Pressurised Water Reactor
RHWG	Reactor Harmonisation Working Group (WENRA)
SAP	Safety Assessment Principle
TAG	Technical Assessment Guide
VWSG	Vibrating Wire Strain Gauge
WENRA	Western European Nuclear Regulators' Association