NUCLEAR DIRECTORATE

GENERIC DESIGN ASSESSMENT – NEW CIVIL REACTOR BUILD

STEP 3 CIVIL ENGINEERING AND EXTERNAL HAZARDS ASSESSMENT OF THE WESTINGHOUSE AP1000

DIVISION 6 ASSESSMENT REPORT NO. AR 09/034-P

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EXECUTIVE SUMMARY

Westinghouse Electric Company LLC (WEC) has submitted a safety case for its AP1000 nuclear power reactor under the Generic Design Assessment (GDA) being carried out by the Nuclear Directorate of HSE and by the Environment Agency. This report:

- summarizes the WEC civil engineering and external hazards submission, as presented in WEC AP1000 Pre-Construction Safety Report (PCSR) and supporting documents;
- and, presents the findings of the civil engineering and external hazards assessment undertaken as part of Step 3 of the Health and Safety Executive's (HSE) Generic Design Assessment (GDA) process.

The Safety Assessment Principles (SAP) have been used as the basis for the assessment of civil engineering and external hazards associated with the AP1000 design. The SAPs require that the integrity of structural components such as steel-framed buildings, crane supports, concrete structures, masonry, foundations, embankments, slopes, river and coastal defences on a nuclear power plant or nuclear chemical plant site be identified and considered in safety assessments. The SAPs further require that external hazards that could affect the safety of the facility should be identified and treated as events that can give rise to possible initiating faults.

At the time of writing I am expecting further documentation related to:

- External hazards;
- Codes and Standards;
- Safety categorisation.

Identifying the most relevant documents for my assessment has been hindered by the apparent absence of a logical hierarchical structure between documents.

Some of the civil engineering and external hazard matters arise directly from the concept design and structural form adopted, but the reasons for choosing these options are outside the scope of this assessment.

Moving from concept design onto layout, WEC needs to consider whether the layout provides adequate segregation in the context of external hazards and ability to withstand internal hazards.

The Shield Building has a transition both in plan and in elevation between conventional reinforced concrete (RC) and steel-concrete-steel sandwich (SCS) sections of the Shield Wall, which can be expected to have different stiffness properties, and which will cause both transverse and torsional asymmetry and amplification of seismic response. The transition also requires robust detailing between the RC and SCS sections. There is a similar transition in the Auxiliary Building. The details of such transitions are important.

WEC itself is reviewing its categorisation and classification of safety systems, and an important report on this is awaited. The safety categorisation system is based on USA practice and needs further study following receipt of the Safety categorisation report. The assignment of the Radwaste Building as category C-III needs further consideration.

The currency of superseded standards used in the design of AP1000 should be addressed following receipt of the Codes and Standards report.

It appears that the lack of an appropriate design code for the SCS sandwich modular construction proposed for AP600, and now AP1000, was recognized over a decade ago, but has not been addressed. At present WEC is stating that the design is to ACI 349. I am wary of false comfort being taken from a claim that a design is to a particular code or standard used outside its scope of applicability. Amongst my technical concerns are transverse shear (the cross frames of angle section members being quite widely spaced), in plane shear (the composite studs not being through-going), and the effect of thermal loads on the plate to concrete bond. A significant WEC

document concerning the design of the Enhanced Shield Building was received on 7 September 2009 (too late to be properly considered in this assessment). No Technical Support Contractor (TSC) approved reports have been received at the time of writing. However, in September 2009 it became apparent that although NRC's vires is mainly limited to the Enhanced Building Shield Wall, its lead civil engineer on AP1000 and I had similar concerns in relation to the SCS modules.

I had been concerned that WEC had been unable to supply a design methodology for the SCS modules which would have been made available to its design contractors in advance of the design. This raised concern that WEC has not been controlling its contractors appropriately. However, at a late stage (6 October 2009) in writing this report I was made aware of and received such a design methodology for SCS modules, though too late to do other than acknowledge its existence. This allays my concern of an apparent lack of a pre-ordained design methodology and clear acceptance criteria. I have planned design audits, and will use these to determine the compliance of the designs with this design methodology.

The amount of work required by myself and TSCs in relation to civil engineering design methodology must not be underestimated.

Turning to external hazards WEC states the design conditions applied to the plant and in addition identify those aspects which will require further consideration once a site or sites have been identified. I see the range of hazards considered as reasonable, except there does not appear to be a consideration of lightning or malicious acts (other than malicious large commercial aircraft) as external hazards. In addition, there is no specific recognition of climate change as a driver for a number of hazards. The current list of hazards recognises that some cannot be defined until a site (or sites) have been defined. For other hazards, limiting values are provided. I am deferring this assessment pending receipt of the External Hazards Topic Report. However, I observe from a scoping document for the Topic report a tendency for WEC to screen out hazards, rather than demonstrate how the safety functional performance of a safety component is to be delivered. Common cause failure needs to be addressed. We have recently conveyed UK expectations regarding resilience against impact from a large commercial aircraft and are awaiting a response.

WEC states that in the UK civil regulatory framework, there is no explicit requirement for construction verification, this being regarded as part of commissioning. I have informed WEC that on the contrary nuclear safety regulation in the UK places a similar level of importance on construction verification as it does on civil engineering design. I have requested that this is addressed in the next issue of the PCSR.

It remains to be shown that the combined effects of design code (or other design methodology), loads, analysis, modelling and construction verification together deliver the required reliability.

The plans in the PCSR are considered adequate at this stage in respect of civil engineering provision for decommissioning.

LIST OF ABBREVIATIONS

ACI	American Concrete Institute
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
ALARP	As Low as Reasonably Practicable
ASCE	American Society of Civil Engineers
ASTM	originally known as the American Society for Testing and Materials
AWS	American Welding Society
BMS	(Nuclear Directorate) Business Management System
DCD	Design Control Document
EA	The Environment Agency
GDA	Generic Design Assessment
HSE	The Health and Safety Executive
HVAC	Heating, Ventilation and Air Conditioning
IAEA	The International Atomic Energy Agency
IRWST	In-containment Refuelling Water Storage Tank
LC	(Nuclear Site) Licence Condition
NCIG	National Construction Issues Group
ND	The (HSE) Nuclear Directorate
NRC	Nuclear Regulatory Commission
OCNS	Office for Civil Nuclear Security
PCCWT	Passive Containment Cooling Water Tank
PCER	Pre-construction Environment Report
PCS	Passive Cooling System
PCSR	Pre-construction Safety Report
RC	Reinforced concrete
RI	Regulatory Issue
RIA	Regulatory Issue Action
RO	Regulatory Observation
ROA	Regulatory Observation Action
RP	Requesting Party
SAP	Safety Assessment Principle
SCS	Steel – concrete - steel
SDC	Seismic Design Category
SSC	System, Structure and Component

LIST OF ABBREVIATIONS

TAG	(Nuclear Directorate) Technical Assessment Guide
TQ	Technical Query
WEC	Westinghouse Electric Company LLC
WENRA	The Western European Nuclear Regulators' Association

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1 INTRODUCTION

1 This reports presents the findings of the civil engineering and external hazards assessment of the Westinghouse AP1000 Pre-Construction Safety Report (PCSR) (Ref. 1) undertaken as part of Step 3 of the HSE Generic Design Assessment (GDA) process. It follows on from a previous report (Ref. 31) written at the end of Step 2. Step 3 assessment has been undertaken on the basis of a Project Initiation Document (Ref. 30) and in line with the requirements of the Business Management System (BMS) document AST/001 (Ref. 21) and its associated guidance document G/AST/001 (Ref. 20). AST/001 sets down the process of assessment within the Nuclear Directorate (ND) and explains the process associated with sampling of safety case documentation. The Safety Assessment Principles (SAP) (Ref. 19) have been used as the basis for the assessment of civil engineering and external hazards associated with the AP1000 design. The SAPs require that the integrity of structural components such as steel-framed buildings, crane supports, concrete structures, masonry, foundations, embankments, slopes, river and coastal defences on a nuclear power plant or nuclear chemical plant site be identified and considered in safety assessments. The SAPs further require that external hazards that could affect the safety of the facility should be identified and treated as events that can give rise to possible initiating faults. Ultimately, the goal of assessment is to reach an independent and informed judgment on the adequacy of a nuclear safety case.

2 During the assessment I became aware that there were significant issues in relation to SAP ECS.5, which deals with situations where there is an absence of an applicable code or standard. This had not been identified in the Step 2 Report as likely to be an issue, but the design methodology, and its justification, of steel-concrete-steel (SCS) sandwich construction has emerged as the major work stream in my assessment.

2 REQUESTING PARTY'S SAFETY CASE

2.1 Documentation

3 Westinghouse Electric Company LLC (WEC) has set out its safety case for AP1000 UK GDA Step 3 Assessment in the UK PCSR (Ref. 1) with five supporting documents (Refs 2 to 6) in the topics of civil engineering and external hazards. Separately there is a European Design Control Document (DCD) (Ref. 7), which is closely based on the US DCD Revision 17. For practical purposes Ref. 7 follows the format and content guidance of Ref. 33, and I have not made significant dependence on it in this assessment, but used the UK PCSR in preference. The WEC submission for Step 3 included thirty five further Technical Reports, of which Refs 9 and 10 are relevant to the current topic areas.

4 The Step 3 submission included a further four documents potentially relevant to civil engineering and external hazards, concerning wind tunnel tests for AP600. These latter documents have not been considered in Step 3.

5 I have obtained, either as a result of a Technical Query (TQ), or as a document offered by Westinghouse further documents (Refs 11 to 19). Ref. 15 was received on 7 September 2009, too late to be considered in this assessment, although its subject (Design of the Enhanced Shield Building) is highly significant, given the apparent absence of a design code for the SCS sandwich construction. The External Hazards Topic Report (Ref. 19) was submitted as a draft/synopsis, while undergoing reviews at Rolls Royce, Westinghouse, and its supporting utilities, on 1 September, with an anticipated approved version to be submitted in October, but again this is too late to be considered in this assessment.

2.2 Description of Civil Structures

6 The following drawing is taken from Ref. 1:

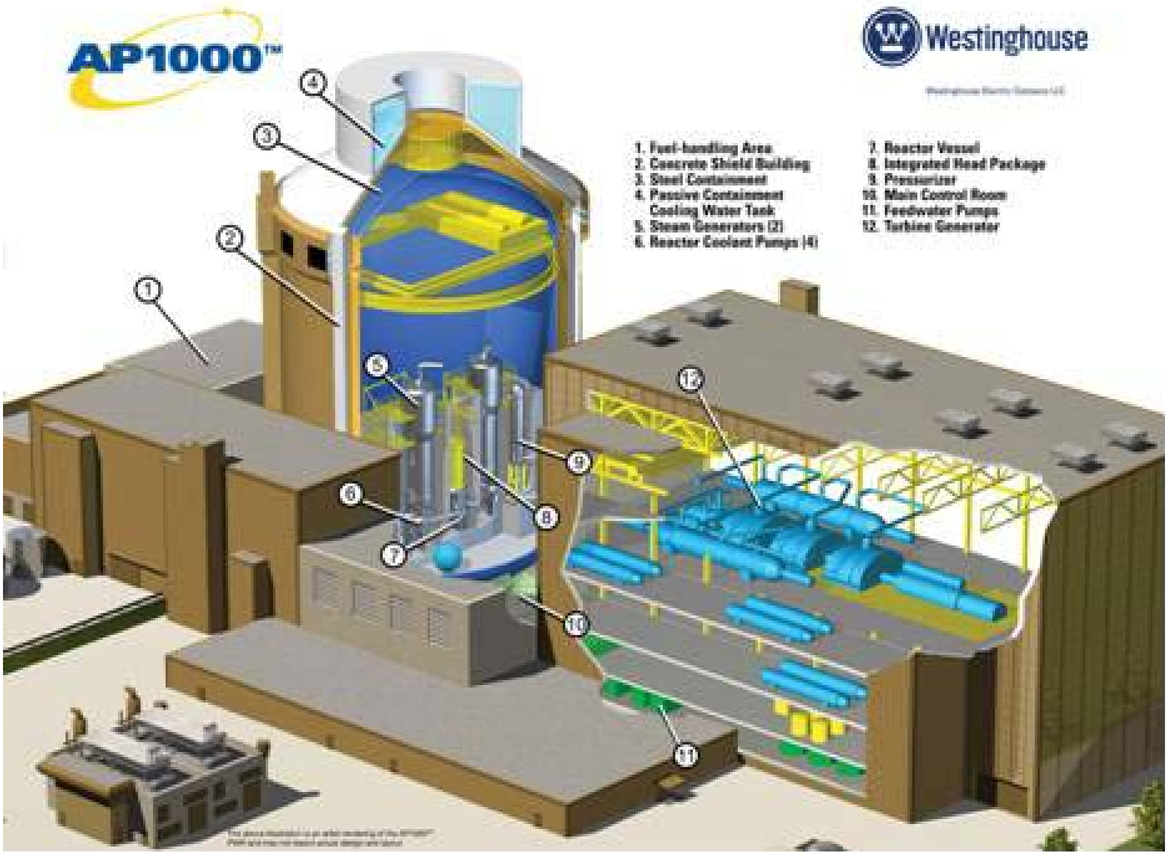

Figure 1 General layout of the AP1000 Plant

7 The following description of the civil structures is taken from the PCSR (Ref. 1).

2.2.1 General Arrangement and Building Functions

8 The plant arrangement consists of five principal building structures;

- The nuclear island (Shield building plus Auxiliary building);
- The annex building;
- The diesel generator building;
- The radwaste building;
- The turbine building.

9 The nuclear island consists of a free-standing steel containment vessel, a concrete shield building, and an auxiliary building. The foundation for the nuclear island is an integral base-mat which supports these buildings.

10 The annex building includes functions such as the health physics area, the control support area, access control, and personnel facilities (shower and locker rooms).

11 The diesel generator building houses two diesel generators and their associated heating, ventilation and air conditioning equipment.

12 The radwaste building contains facilities for the handling and storage of plant wastes.

13 The turbine building contains the turbine generator.

14 The transformer area is located immediately adjacent to the turbine building.

15 WEC differentiate between Safety and non-Safety related systems (for further detail, see Section 3.6.2 below). WEC state that the plant arrangement provides separation between Safety-Related and non-Safety-Related systems to preclude adverse interaction between Safety-Related and non-Safety-Related equipment. All Safety-Related systems are contained in the nuclear island; the turbine, annex, diesel generator and radwaste buildings contain only non-Safety-Related systems. Separation between redundant Safety-Related equipment and systems provides confidence that the safety design functions can be performed. In general this separation is provided by partitioning an area with concrete walls.

2.2.2 Containment Building

16 The Containment Building (a seismic Category I structure) is a freestanding cylindrical steel Containment Vessel with elliptical upper and lower heads providing a high degree of leak tightness. It is surrounded by a seismic Category I reinforced concrete Shield Building. There are two floor elevations (grade access maintenance floor and operating deck) and four lower equipment compartments within the Containment Building. Removable hatches are provided for access to equipment at other elevations.

17 The Shield Building is the structure that surrounds the Containment Vessel. During normal operations, a primary function of the Shield Building is to provide shielding for the Containment Vessel and the radioactive systems and components located in the Containment Building. The Shield Building is a seismic Category I reinforced concrete structure. It shares a common basemat with the Containment Building and the Auxiliary Building. All items comprising the passive cooling system (PCS) are located within the Shield Building. The following items represent the significant features of the Shield Building and the annulus area:

- Shield Building cylindrical structure
- Shield Building roof structure
- Lower annulus area
- Middle annulus area
- Upper annulus area
- PCS air inlet
- PCS air inlet plenum
- PCS water storage tank
- PCS air diffuser
- PCS air baffle

18 The cylindrical section of the Shield Building serves as both shielding and as a missile barrier. It is also a key component of the PCS. It structurally supports the roof and is a major structural member for the entire Nuclear Island. Floor slabs and structural walls of the Auxiliary Building are structurally connected to the cylindrical section of the Shield Building. The Shield Building roof is a reinforced concrete conical shell supporting the PCS water storage tank and air diffuser. Air intakes are located at the top of the cylindrical portion of the Shield Building. The conical roof supports the PCS water storage tank which is constructed with a stainless steel liner attached to reinforced concrete walls.

19 The containment internal structures are those concrete and steel structures inside (not part of) the containment pressure boundary that support the RCS components and related piping systems and equipment. The concrete and steel structures also provide radiation shielding. The containment internal structures consist of the primary shield wall, reactor cavity, secondary shield walls, In-containment Refuelling Water Storage Tank (IRWST), refuelling cavity walls, operating floor, intermediate floors and various platforms. The containment internal structures are designed using reinforced concrete and structural steel. At the lower elevations conventional concrete and reinforcing steel are used, except that permanent steel forms are used in some areas in lieu of removable forms based on constructability considerations. Walls and floors are concrete filled steel plate structural modules. The walls are supported on the mass concrete containment internal structures basemat with the steel surface plate extending down to the concrete floor on each side of the wall. The steel surface plates of the structural modules provide reinforcement in the concrete. Concrete is used where required for shielding, but reinforcing steel is not normally used. Walls and floors exposed to water during normal operation or refuelling are constructed using stainless steel plates.

2.2.3 Auxiliary Building

20 The primary function of the Auxiliary Building is to provide protection and separation for the seismic Category I mechanical and electrical equipment located outside the Containment Building. The most significant equipment, systems, and functions contained within the Auxiliary Building are the following:

- Main Control Room
- Class 1E instrumentation and control systems
- Class 1E electrical system
- Fuel handling area
- Mechanical equipment areas
- Containment penetration areas
- Main steam and feedwater isolation valve compartment

21 The Auxiliary Building is a seismic Category I reinforced concrete structure. It shares a common basemat with the Containment Building and the Shield Building. The Auxiliary Building wraps around approximately 70% of the circumference of the Shield Building. Floor slabs and the structural walls of the Auxiliary Building are structurally connected to the cylindrical section of the Shield Building.

22 Structural modules are used for part of the south side of the Auxiliary Building. These structural modules are structural elements built up with welded steel structural shapes and plates. Concrete is used where required for shielding, but reinforcing steel is not normally used. These modules include the spent fuel pool, fuel transfer canal, and cask loading and cask washdown pits.

2.2.4 Annex Building

23 The Annex Building provides the main personnel entrance to the power generation complex. It includes access ways for personnel and equipment to the clean areas of the Nuclear Island in the Auxiliary Building and to the radiological control area. The building includes the health physics facilities for the control of entry to and exit from the radiological control area as well as personnel support facilities such as locker rooms. The building also contains the non-1E AC (i.e. not a Class 1 piece equipment in NRC

terminology) and dc electric power systems, other electrical equipment, the control support area and various HVAC systems. The Annex Building is a combination of reinforced concrete structure and steel framed structure with insulated metal siding. Floor and roof slabs are reinforced concrete supported by metal decking. Floors are designed to act as diaphragms to transmit horizontal loads to side wall bracing and to concrete shear walls. The building foundation is a reinforced concrete mat.

24 That part of the annex building adjacent to the nuclear island is classified as seismic category II and is analysed and designed to prevent its collapse under the safe shutdown earthquake. The rest of the annex building area is designed to Uniform Building Code requirements (Ref. 41) – see “Seismic Category III”, Section 3.7.2.3 below.

2.2.5 Diesel Generator Building

25 The diesel generator building houses two identical slide-along diesel generators separated by a three hour fire wall. These generators provide backup power for plant operation in the event of disruption of normal power sources. The diesel generator building is classified as non seismic and is designed as a structure subject to wind loads in accordance with the Uniform Building Code. The building is not located adjacent to the nuclear island and diesel generators supply only selected plant non-Safety-Related a.c. loads. The building is a single storey steel framed structure with insulated metal siding. The roof is composed of a metal deck supporting a concrete slab and serves as a horizontal diaphragm to transmit lateral loads to sidewall bracing and thereby to the foundation. The foundation consists of a reinforced concrete mat.

2.2.6 Radwaste Building

26 The Radwaste Building includes facilities for segregated storage of various relatively low level categories of waste prior to processing, for processing by mobile systems and for storing processed waste in shipping and disposal containers. The Radwaste Building is non seismic and is designed to Uniform Building Code (Ref. 41) requirements. The liquid radwaste processing areas are designed to contain any liquid spills, including a raised perimeter and floor drains that lead to the liquid radwaste system waste hold-up tanks. The foundation for the entire building is a reinforced concrete mat.

2.2.7 Turbine Building

27 The Turbine Building houses the main turbine, generator and associated fluid and electrical systems. It provides weather protection for the laydown and maintenance of major turbine / generator components. The Turbine Building also houses the makeup water purification system. The Turbine Building is a non-seismic steel column and beam structure that has been designed to Uniform Building Code (Ref. 41) requirements. The Turbine Building ground floor (structural mat) is a reinforced concrete slab.

2.3 Standards and Criteria

28 The PCSR (Ref. 1) notes that the European DCD (Ref. 7) Chapter 3 Section 3.1 discusses the extent to which the AP1000 design criteria for Safety-Related structures, systems and components comply with the Nuclear Regulatory Commission General Design Criteria.

29 Ref. 1 states that the following documents are applicable to the design, materials, fabrication, construction, inspection, or testing of the containment internal structures, which are Category I:

- American Concrete Institute (ACI), Code Requirements for Nuclear Safety-Related Structures, ACI-349-01 (Ref. 38)
- ACI, Detailing Manual, 1994
- ACI, Standard Specifications for Tolerances for Concrete Construction and Materials, ACI-117-90
- ACI, Guide to Formwork for Concrete, ACI-347-94
- AISC Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities, AISC-N690-1994
- American Welding Society (AWS), Structural Welding Code, AWS D 1.1-2000
- AWS, Reinforcing Steel Welding Code, AWS D 1.4-98
- National Construction Issues Group (NCIG), Visual Weld Acceptance Criteria for Structural Welding at Nuclear Power Plants, NCIG-01, Revision 2, May 7, 1985.

30 The other seismic Category I structures are the Shield Building and the Auxiliary Building. Ref. 1 states that following standards are applicable to the design, materials, fabrication, construction, inspection or testing:

- ACI, Code Requirements for Nuclear Safety-Related Structures, ACI-349-01
- ACI, ACI Detailing Manual, 1994
- AISC Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities, AISC-N690-1994
- American Iron and Steel Institute (AISI), Specification for the Design of Cold Formed Steel Structural Members, Parts 1 and 2, 1996 Edition and 2000 Supplement
- AWS, Structural Welding Code, AWS D 1.1-2000
- AWS, Reinforcing Steel Welding Code, AWS D 1.4-98
- NCIG, Visual Weld Acceptance Criteria for Structural Welding at Nuclear Power Plants, NCIG-01, Revision 2, May 7, 1985

31 Ref. 13 sets out the design criteria that are to be used in the design of structures for the AP1000. It states that these design criteria follow recognized codes whenever they are applicable to the work.

2.4 External Hazards

32 Ref. 1 notes that the site-specific PCSR must demonstrate to the UK regulator that the potential operating organisations can make and satisfy various claims as to safety prior to beginning construction of an AP1000 built on a specific UK site. It states that all external hazards will need to be reviewed with respect to site-specific aspects. This may result in modifications to the hazards listing and the Fault Schedule, which will both support site-specific PCSRs. The issues to be addressed include:

- Magnitude and frequency of expected earthquakes.
- Likelihood of loss of grid.
- Likelihood of external flooding, given the expected rainfall pattern and local topography, tidal events and storm surges.
- Likelihood of severe winds.
- Likelihood of extreme ambient temperatures

- Proximity to civil airports, military airbases and air corridors.
- Nearby gas and oil storage depots.
- Nearby factories and ports, where hazardous activities might take place.
- Nearby train lines or roads, over which hazardous material could be carried.

2.5 Load Combinations, Design and Analysis Procedures

33 Ref. 13 states that the steel structures and components are designed according to the elastic working stress design methods of the AISC-N690 specification. The concrete structures and components are designed according to the strength design methods of Ref. 38. The design and analysis procedures for the seismic Category I structures (other than the Containment Vessel and containment internal structures), including assumptions on boundary conditions and expected behaviour under loads, are in accordance with ACI-349 for concrete structures, with for steel structures and AISI (for cold formed steel structures. The criteria of ACI-349, Chapter 12, are applied in development and splicing of the reinforcing steel. The ductility criteria of ACI-349, Chapter 21, are applied in detailing and anchoring of the reinforcing steel.

2.6 Construction

34 Ref. 1 states that the WEC AP1000 design employs construction methods and a plant layout which are conducive to safe operations during construction. Much of the design is modular which allows the build and test of sub assemblies to be undertaken in a factory environment. This approach reduces site construction and the risks from those activities. Modular construction in a factory environment also has a positive effect on product quality that has a downstream effect on safety and reduced maintenance requirements during the operation of the plant.

35 It further states that in the UK civil regulatory framework, there is no explicit requirement for construction verification, this being regarded as part of commissioning.

3 NUCLEAR DIRECTORATE ASSESSMENT

3.1 Requesting Party's Safety Case

36 The extent of the safety case set out by WEC and considered in this assessment is laid out in Section 2.

37 At the time of writing I am expecting the following further WEC reports in the next two months:

- External Hazards Topic report;
- Codes and Standards report;
- Safety Categorisation report.

38 I have been hindered in identifying the most relevant documents for my assessment by the apparent absence of a logical hierarchical structure between documents.

3.2 ND Assessment Standards and Criteria

39 For my assessment I have principally followed the SAPs (Ref. 19) and associated Technical Assessment Guides (Refs 24 to 29). The assessment process broadly follows

Refs 20 to 23, as modified by GDA specific instructions. I am informed by IAEA guidance (Ref. 36).

3.3 Technical Queries and Regulatory Observations

40 During my assessment I have raised seven Technical Queries (TQs) and one Regulatory Observation (RO). The date, title and a status i.e. open or closed, of Regulatory Observations are shown in Annex 1. Schedules of all TQs raised concerning AP1000 during Step 3 are maintained in Ref. 44, and of all ROs in Ref. 45.

3.4 Concept Design

3.4.1 Assessment Criteria

41 Under the heading *"Safety Case Characteristics"* the SAPs para. 93 envisages that to demonstrate 'as low as is reasonably practicable' (ALARP) has been achieved for new facilities, modifications or periodic safety reviews, the safety case should identify and document all the options considered. Good practice in the UK nuclear industry is to present a range of credible options and to demonstrate that the chosen concept design is ALARP.

3.4.2 Assessment of WEC's Concept Design

42 Some of the civil engineering and external hazard matters arise directly from the concept design and structural form adopted, but the reasons for choosing these options are outside the scope of this assessment, for which ALARP is not to constrain the concept design, but to ensure that any Reasonably Practicable improvements have been made.

43 Ref. 1 states that the design of the plant has been optimally selected from a range of technically viable concepts, and Section 9 of Ref. 1 sets out the ALARP case.

44 The Passive Containment Cooling Water Tank (PCCWT) holds approximately 755,000 gallons of water (Ref. 6 states approximately 780,000 gallons) and is required for containment cooling following a design basis accident. I have sought confirmation from WEC that this is 755,000 US liquid gallons, which would amount to about 2858 tonnes of water. This is a significant structural load.

45 The arrangement leads to:

- the PCCWT as a potential missile directly above the containment and RPV;
- the dependence of the PCCWT on the structural integrity of the Enhanced Shield Wall, for which WEC proposes in part to use an innovative form of construction;
- the elevation of the high mass PCCWT at the top of the Enhanced Shield Wall forming an inverted pendulum, a well known seismic vulnerability.

46 The scope of this assessment does not include looking at alternative design concepts. Some of the civil engineering and external hazard matters arise directly from the concept design adopted.

47 At a more detailed level of concept design the absence of visible optioneering is evident in WEC's adoption of steel-concrete-steel (SCS) sandwich modular construction in lieu of, say, conventional reinforced concrete for some of the key structures on the nuclear island. Another area of the concept design that might have been explored at optioneering stage to demonstrate ALARP is the pitched, rather than domed, roof to the Enhanced Shield Building. My judgement is that a domed roof would be more expensive and time

consuming to construct, but would have mitigated the structural load path between the pitched roof and the annular wall

3.5 Layout

3.5.1 Assessment Criteria

48 The layout SAPs (ELO.1 to ELO.4) give guidance mainly related to:

- facilitation of necessary access for operation, maintenance, inspection and testing;
- unauthorised access;
- movement of nuclear matter;
- and, minimization of the effects of incidents.

3.5.2 Assessment of WEC's Layout

49 I note that the equipment (e.g. the Reactor Coolant Drain Tank) in the in-containment structures is fairly tightly packed, possibly as a result of scaling up from AP600 to AP1000 while keeping the structures similar. This has implications for access for operation, maintenance, inspection and testing, plus potentially the dose to workers.

50 Unauthorised access is a matter for the Office for Civil Nuclear Security (OCNS), although malicious acts are an external hazard.

51 WEC needs to consider whether the layout provides adequate segregation in respect of external hazards. Segregation for internal hazards is a matter for the internal hazards assessment, but the civil engineering structures are required to provide appropriate barriers, so that segregation of safety systems is achieved where claimed.

52 A final aspect of layout is that of the regularity of the structural form, following closely on from structural design concept. Simplicity of structural form is a known contributor to robustness. The shield building surrounds the containment vessel and shares a common basemat with the containment vessel and the auxiliary building. The Shield Building is partially enclosed within the Auxiliary building, a layout that introduces some asymmetry of mass and stiffness. The cylindrical wall section that is below the auxiliary building roof line is a reinforced concrete (RC) structure. The section that is not protected by the auxiliary building is a composite steel and concrete (SCS) structure. Thus there is a transition both in plan and in elevation between RC and SCS sections, which can be expected to have different stiffness properties, and which will cause both transverse and torsional asymmetry and amplification of seismic response. The transition also requires robust detailing between the RC and SCS sections. There is a similar transition in the Auxiliary Building, in which structural modules are used on the south side between elevations 66'-6" to elevation 135'-3".

3.6 Safety Categorisation

3.6.1 Assessment Criteria

53 The SAPs (ECS.1 and ECS.2, and paras 148 to 155) are the primary guidance to the assessment of safety categorisation, and I have not made use of the TAG (Ref. 24).

54 The SAPs link the selection of design standard to safety categorisation.

55 ECS.1 suggests, though not exclusively, three different levels of safety categorisation.

3.6.2 Assessment of WEC Safety Categorisation

56 Ref. 1 assigns Systems, Structures and Components (SSCs) a Seismic Design Category (SDC) that is a function of the severity of adverse radiological and toxicological effects from the hazards that may result from the seismic failure of SSC on workers, the public and the environment. This system is embedded in nuclear regulation system in the USA (Ref. 46), which sets out a method that the staff of NRC considers acceptable for use in identifying and classifying those features of light-water-reactor (LWR) nuclear power plants that must be designed to withstand the effects of the SSE.

57 WEC has designated structures as:

- Seismic Category I (C-I) applies to function and integrity;
- Seismic Category II (C-II) applies only to integrity;
- Seismic Category III (C-III) applies to investment protection for non-safety related building structures;
- Non-seismic applies to all items not classified as Seismic Category I, II or III.

58 The WEC categorisation system does not align well with the SAP ECS.1. At the time of writing I am awaiting a document from WEC concerning safety categorisation.

59 The major APl000 structures are classified (Ref. 13) as below:

- Nuclear Island C-I
- Basemat C-I
- Containment Interior C-I
- Shield Building C-I
- Auxiliary Building C-I
- Containment Air Baffle C-I
- Shield Building Stairs and Elevators C-II
- Turbine Island C-III
- Radwaste Building C-III
- Diesel-Generator Building C-III
- Circulating and Service Water Pumphouse C-III
- Circulating Water Pump Basin C-III
- Other Buildings
  - i) Cooling Towers C-III
  - ii) Water Service Building C-III
  - iii) Administration Building C-III
  - iv) Warehouse and Shops C-III
  - v) Security Control Building C-III
- Annex Building Columns A-D C-III
- Annex Building Columns E-I C-II

60 The assignment of the Radwaste Building as category C-III needs further consideration when details of its inventory and release potential are known.

3.7 Design Standards and Criteria

3.7.1 Assessment Criteria

61 The SAPs (ECS.3 to ECS.5, and paras 157 to 161) are the primary guidance to the assessment of safety categorisation. I have not made use of the TAG (Ref. 24), as it is significantly out of date.

62 SAPs paras 158 and 159 advise that appropriate national or international codes and standards should be adopted for Classes 1 and 2 of structures, systems and components; for Class 3, appropriate non-nuclear-specific codes and standards may be applied; codes and standards should be preferably nuclear-specific codes or standards leading to a conservative design commensurate with the importance of the safety function(s) being performed.

63 The term 'international code' in the SAPs needs some explanation. International Standards Organization (ISO) standards represent a consensus view and to achieve this do not necessarily meet the reliability expectations for nuclear structures.

64 ND does not prescribe what design codes should be used in the UK, and indeed accepts (ECS.5) that there may be circumstances in which there is no relevant design code. While there may be a requirement under the Public Procurement Regulations for normal publically funded structures to be designed to the structural Eurocodes, as these and their National Annexes become available and the corresponding British Standards are declared obsolete, I am not anticipating that AP1000 will be publically funded in the UK. In any event EN 1998-1-1 1996 states that special structures with increased risks for the population, such as nuclear power plants and large dams, are beyond its scope, while EN 1990:2002 notes that for the design of special construction works (e.g. nuclear installations, dams, etc), other provisions than those in EN 1990 to EN 1999 might be necessary. Thus USA codes may be used for nuclear structures in the UK if appropriate.

3.7.2 Assessment of WEC Design Standards

3.7.2.1 High Level Requirements

65 Table 2 of the Civil/Structural Design Criteria (Ref. 13) sets out three high level requirements associating Safety Categorisation with specified design standards:

- Seismic Category I (excluding the containment structure): ACI 349 (for concrete structures), AISC-N690 (for steel structures), ASCE-7 (for loads), ASCE-4 (for seismic design and analysis;
- Seismic Category II: ACI 349 (for concrete structures), AISC-N690 (for steel structures), ASCE-7 (for loads), ASCE-4 (for seismic design and analysis);
- Seismic Category III: ACI 318 (for concrete structures), AISC-S335-ASD, AISC-LRFD (for steel structures), ASCE-7 (for loads), UBC (for seismic design and analysis);

66 Although the Seismic Category II structures are designed to the same standards as the Seismic Category I, they may be constructed to the codes and standards for Seismic Category III structures.

3.7.2.2 Currency of WEC's Design Standards

67 I note that a number of the standards cited by WEC, and at least one NRC Regulatory Guide (Ref. 46) have now been superseded. ND normally expects the current version of design standards to be used up to the establishment of a Reference Design or Design Freeze, and that any significant changes between that point and the submission of request for Consent to Construct under LC 19 should be evaluated for their significance.

Indeed, one of the objectives (Ref. 47) of a Periodic Safety Review under LC 15 is that reviews should include as a minimum changes in safety standards or safety methodology/ assumptions. WEC has stated that it intends submitting a report in autumn 2009 concerning codes and standards, and the question of the currency of older standards used in the design of AP1000 should then be addressed.

3.7.2.3 Category III Structures

68 Category III Buildings include the Turbine Island, Radwaste Building, Diesel generator Building, Circulating and Service Water Pump House and parts of the Annex Building.

69 The Turbine Building is located adjacent to the nuclear island, and if it collapsed could threaten the safety functional performance of various SSCs. Although it is Seismic Design Category III, WEC has designed it to seismic Category I structure tornado loading. As applied to the Turbine Building, it appears to be intended that the Turbine Building does not have any particular performance criteria under extreme natural hazards, but should not so deform or collapse under seismic or tornado loading such as to jeopardise any SSCs on the nuclear island.

70 The current version of the Uniform Building Code (Ref. 41) used for the design of the Turbine Building, is now known as the International Building Code. It is mainly used in North America for buildings, excluding small family dwellings. It includes measures for fire protection and for seismic design for non-safety critical facilities.

71 I am unclear as to why the Turbine Building is designed against a Tornado (an extreme wind), but only to normal industrial standards for seismic loads.

72 WEC has designed seismic Category III structures to Ref. 39. I consider this acceptable, and there is UK precedence for this.

3.7.2.4 Category II Structures

73 The only Category II structures are:

- The Shield Building Stairs and Elevators;
- The Annex Building between columns E and I.

74 WEC has specified that Seismic Category II structures shall be designed to meet the requirements of ACI 349 (Ref. 38) for concrete structures and AISC-N690 (Ref. 37) for the steel structures. However, the structure is constructed to the same requirements as the non-seismic structures, ACI 318 (Ref. 39) for concrete structure and AISC-S335 for steel structures. Less onerous loads are applied and reduced standards of construction inspection. As a general principle I would wish to investigate the less onerous loads used in the design and the reduced standards of construction. However, concerning the first group of structures WEC has designated as Category II (the Shield Building stairs and elevators) I consider this acceptable for items which will probably be obtained form normal industrial sources, rather than designed and manufactured to nuclear standards.

3.7.2.5 Category I Structures

75 For Category I structures (e.g. Containment Internal Structures, Shield Building, Auxiliary Building) WEC has adopted the following principal design standards:

- AISC-N690-1994 for steel structures;
- and, ACI-349-01 for its reinforced concrete structures.

76 For certain localised stresses under thermal loading WEC has used alternative acceptance criteria based on the AMSE Code (Ref. 40).

77 Successive editions of ACI-349 and AISC-N690 have been used by the UK nuclear industry; indeed ACI-349 is probably the most widely used design standard for reinforced concrete nuclear structures in the UK. Some adaption is required, e.g. in respect of non-USA material specifications and in materials testing, but it as generally been found acceptable to ND. There has generally been at least one UK committee member on the ACI-349 committee for the last two decades, and it can be regarded as being an international code.

78 Thus I would not have an issue with the appropriate application of ACI-349-01, or more preferably the current version ACI 349-06, to the design of Category 1 civil structures of AP1000. Regrettably, in my opinion in the case of SCS modules WEC is using the ACI design standard outside its scope of application. Subsequently I found Refs 32 and 34.

79 Ref. 34 considered the assessment of modular construction for safety-related structures at advanced nuclear power plants. It is a comprehensive review at the time (1997). It considers the successful use of structural modules in other industries, and in varying degrees in the nuclear industries of some countries. It recognizes capital cost savings, reduction in construction time, potential quality improvements, various outstanding technical issues, and the lack of codes and standards for certain types of module.

80 NRC (Ref. 32) sets out guidance to licensees and applicants on methods acceptable to NRC staff for complying with NRC's regulations in the design, evaluation and quality assurance of safety related nuclear concrete structures, excluding concrete reactor vessels and containments. Ref. 32 discusses and defines fifteen Regulatory Positions on the use of ACI 349-97, of which Regulatory Position 13 is:

- The design of composite members used in modular construction should conform to the intent of Code provisions of Chapter 10.14 and Chapter 17 of ACI 349 (i.e. the same rules used in computing the strength of regular reinforced concrete should apply). Until ACI 349-97 contains more specific requirements for modular construction, future designs will be evaluated on a case-by-case basis.

81 The discussion on this Regulatory Position is that:

- This position is intended as a guide until ACI 349-97 addresses composite or modular construction.

82 Ref. 35 gives further information on the regulatory position regarding SCS construction.

83 ACI-349-07 Chapter 10.14 is titled *"Composite compression members"*, and this chapter is preserved in WEC's adoption of the more recent ACI-349-02. It does not cover composite shear walls or flexural members. Chapter 17 concerns composite flexural members.

84 Even the more recent ACI 349-06 has not addressed the issue raised by NRC of more specific requirements for modular construction. Thus it appears that the lack of an appropriate code for the SCS sandwich modular construction proposed for AP600, and now AP1000, was recognized over a decade ago, but has not been addressed.

85 I am wary of false comfort being taken from a claim that a design is to a particular code or standard used outside its scope of applicability. Without a code basis clearly demonstrated to apply to a particular design there are significant risks that a structure compliant to the detail of a code may not perform with the reliability intended by appropriate application of the code.

86 Amongst my technical concerns are transverse shear (the cross frames of angle section members being quite widely spaced), in plane shear (the composite studs not being through-going), and the effect of thermal loads on the plate to concrete bond.

87 WEC has widely adopted modular construction in the plant design. Basic modules are factory-built in rail shippable sizes. The structural modules eliminate the need for rebar in the walls. Basic modules are assembled into large modules at the site, which are then lifted into the buildings by heavy lift crane. The modules comprise two plates separated by trusses and with studs at 10 inch spacing. The trusses allow the modules to be handled as temporary structures, but become part of the permanent structure. The stiffeners allow transport of the plates. The modules are designed to be transported on Amtrak rail gauge as 80' x 10' x 10' modules.

88 The section of the Shield Wall that is not protected by the auxiliary building is made up of SCS sandwich modules, where two steel plates act compositely with a thickness of concrete via shear studs. The concrete for the SCS portion is Self-Consolidating Concrete (SCC) with compressive strength, *f'c* = 6,000 psi. The steel surface plates act as concrete reinforcement. Cross frames of angle section (6 inches x 4 inches x 0.5 inches) and shear studs (0.75 inch diameter x 6 inches in length) are welded to the inside faces of the steel faceplates to develop composite behaviour of the steel faceplates and concrete. The vertical angles are spaced at 2.25 degrees and act as shear connectors as well as resisting wet concrete loads during construction. Studs are spaced at 10-inch centres vertically and in two rows at the third points between angles, 0.75 degrees, circumferentially.

89 Unlike conventional RC construction in which the shear links are taken round the longitudinal reinforcement, SCS construction depends on the welding of the shear reinforcment to the steel plates. The welding is under factory conditions, rather than site, with the potential for improved quality. Nonetheless weld design and quality need attention.

90 Design is based on some Japanese testing done in the 1990s, and a draft Japanese design code (Ref. 48). This draft code is dated 1992 and WEC have not referred me to a more recent or approved version of this standard; it does not appear on the list of ten JSCE concrete standards published in English. WEC has verbally informed me that AISC is drafting a document on modular construction for nuclear facilities. I note that AISC-N690-1994 states at Q1.11.1 *"Composite construction shall consist of steel beams or girders supporting a reinforced concrete slab"*. The commentary (CQ1.11.1) extends this scope to include composite beams with formed steel deck, but I do not consider that this includes SCS sandwich modules.

91 However, within the safety case WEC refer not to the AISC code, but to ACI-349, as the design standard for the SCS modules. I raised TQ-AP1000-69 stating that it was not apparent to me that ACI 349-01 was applicable to the modular steel/concrete sandwich form used in AP1000. For example, clause 1.1.7.2 excludes from the scope of ACI 349-01 structural concrete slabs cast on stay-in-place composite steel form deck, which appears to be the structural system described in ACI 349-01 closest to the steel/concrete sandwich form used on AP1000. As some references concerning the design methodology were not forthcoming I transferred the question to TQ-AP1000-143. No suitable response being forthcoming, I raised it to a Regulatory Observation as RO-AP1000-041.A1.

92 Ref. 6 states that additional testing is being performed for confirmation of the strength and ductility of the anchorage between the SCS and RC portions of the enhanced shield building. As part of the test program for the SCS, in-plane and out-of-plane shear plus tension large scale tests are to be conducted.

93 WEC state that SCS construction has been adopted elsewhere for NPP. Evidence of operational experience feedback would strengthen the case for its use on AP1000.

94 I recognize the advantage of modular construction, but the particular SCS sandwich system adopted by WEC will require some effort to be shown to be justified. If I am unable to determine that the methodology or methodologies are justified and have been appropriately implemented by WEC and its contractors, then sample independent design

checks, as for a Category 3 highway or rail bridge may be required. This would not be a trivial task, as formulation of the loads is less straight forward than for a highway or rail bridge.

3.8 Specification of Materials

3.8.1 Assessment Criteria

95 SAP ECE.16 guidance is that:

- Civil construction materials should be compliant with the design methodologies used, and shown to be suitable for the purpose of enabling the design to be constructed, operated, inspected and maintained throughout the life of the facility.

96 Section 4.3 of Ref. 26 notes that:

- Where foreign codes and standards are used, are they compatible for use with UK materials and UK materials practice? (For example compare the use of ACI 318 with the use of UK specified concrete and bar bending shapes.)

3.8.2 Assessment of WEC Specification of Material

97 I understand that it is WEC's intent for AP1000 to be a global design with as much local sourcing and manufacture as reasonably achievable. The AP1000 is designed on the basis that the equipment, modules, structures, and bulk material can be shipped to the site by commercial rail or truck. However, it seems highly likely that most construction materials would be sourced in the UK. One aspect which does not appear to have been recognised is the use of non US materials for construction in the UK. For example, reference is made to ASTM material for the SCS steel plates, angle sections and studs. Whilst this is not seen as a major impediment, the increased globalisation of the supply chain means that the translation of the requirements to more generic basis will be essential.

98 There is a metrication issue, as structural steel plate, structural steel sections, and rebar are metricated in the UK, whereas the WEC design is in Imperial units. Likewise, the number of preferred rebar shapes has been radically reduced in the UK in recent years, and the compliance of the rebar details in AP1000 with Ref. 49 should be considered at design detailing stage.

3.9 Connections and Detailing of the Modules

3.9.1 Assessment Criteria

99 SAP paras 282 and 283 note:

- For structures for which the consequence of failure would be high, predictable, gradual and detectable failure modes for severe loadings.
- Sufficiently high margins may be provided to ensure that, for structure types that are inherently less ductile, failure would be extremely unlikely to occur for credible initiating events.

3.9.2 Assessment of WEC Connections and Detailing of the Modules

100 The weak point of modular construction tends to be the connections. I need to be satisfied how connections between similar and dissimilar modules, and between modules and basemats meet my expectations of:

- Clear load paths;
- Ductile detailing.

101 WEC has developed a two-tiered methodology for anchorage of SCS modules to RC components with offset dowels based on ACI 349 shear-friction based equilibrium. This is supplemented by the deformed rebars development criteria. UK practice is generally to use rebar couplers rather than development length bar splicing.

102 The tension ring and air inlets are designed as an SCS module similar to the rest of the cylindrical wall.

3.10 Outside Advice

103 I am obtaining external advice under TSC contracts on the following aspects of the modular construction:

- A general review of steel/concrete sandwich modular construction, review of the extent to which this is covered by ACI 349-01, subsequent developments of ACI 349. The review will consider published and potentially unpublished information on the available historic and current research, and the use of steel/concrete sandwich modular construction, identifying relevant design standards or guides, and known, potential or suspected problems. The review will consider all relevant aspects of their behaviour and the affect they have on the structural performance, including:
    - Overview of scope of the methodology (inclusions and exclusions)
    - History and status of the methodology
    - Understanding the fundamental principles of the composite structural behaviour
    - Welding and backing strips
    - Connection details
    - Links to ACI 349, ASCE/SEI 43-05, ASCE/SEI 7-05 and NRC RG 1.208
    - Comparison with Eurocode 4
    - Implications of current version of Appendix D of ACI 349
    - Areas of methodology not developed from ACI 349
    - Response to seismic loads
    - Use of country specific loads
    - Construction loads
    - Axial, shear and bending resistance
    - Bond
    - Seismic performance
    - Use of country specific material properties
    - Reliability claims
    - Appropriateness of specified loads, load factors and material factors, including justification of reliability claims, or alternatively in the absence of a reliability claim, assessment of reliability
    - Benchmarking of the methodology against other design methods and against experimental results

- Applications of the methodology in its current form
- ACI 349 developments since 349-01
- Requirement for link or additional longitudinal reinforcement
- Engagement of studs (splitting forces)
- History and status of the methodology, taking account of documents specified to design contractors, and material subsequent changes to referenced design standards.
- Applications of the methodology in its current form
- Construction issues, e.g. verification of adequacy of placement of infill concrete.

104 No approved reports have been received from TSCs at the time of writing.

3.11 Liaison with other Nuclear Safety Regulators

105 In September 2009 I participated in the Second Meeting of the AP1000 Working Group of the Multi Design Evaluation Programme hosted by the Nuclear Energy Agency. One of the two sub-groups for this meeting concerned civil engineering. The principal participants were NRC and ND. The main item discussed was WEC's modular SCS system. NRC is further advanced in its considerations than I am. However, it became apparent that NRC's vires is mainly limited to the Enhanced Building Shield Wall, but that its lead civil engineer for AP1000 and I had similar concerns. NRC is more advanced in its deliberations than I am, and there may be the opportunity to share findings.

106 The meeting concluded by adopting draft technical guidelines for modular (or other innovative) construction technologies. These principles are not specific to AP1000.

3.12 External Hazards

3.12.1 Assessment Criteria

107 SAPs EHA.1 to EHA.15 give examples of the range of external hazards over which a duty holder should demonstrate an effective process to identify external hazards relevant a particular site. EHA.1 states:

- External and internal hazards that could affect the safety of the facility should be identified and treated as events that can give rise to possible initiating faults.

3.12.2 Assessment of WEC's Natural and Non-malicious Man-made Hazards

108 Ref. 1 states the design conditions applied to the plant and in addition identify those aspects which will require further consideration once a site or sites have been identified.

109 Ref. 1 identifies the following list of hazards:

- Magnitude and frequency of expected earthquakes;
- Likelihood of loss of grid;
- Likelihood of external flooding, given the expected rainfall pattern and local topography, tidal events and storm surges;
- Likelihood of severe winds;
- Likelihood of extreme ambient temperatures;
- Proximity to civil airports, military airbases and air corridors;

- Nearby gas and oil storage depots;
- Nearby factories and ports, where hazardous activities might take place;
- Nearby train lines or roads, over which hazardous material could be carried.

110 The range of hazards considered is mainly reasonable, except that there does not appear to be a consideration of lightning or malicious acts (other than malicious large commercial aircraft) as external hazards. In addition, there is no specific recognition of climate change as a driver for a number of hazards. The current list of hazards recognises that some cannot be defined until a site (or sites) have been defined. For other hazards, limiting values are provided. I am deferring this assessment pending receipt of the External Hazards Topic Report, which I expect in October, but am unable to consider in this Step 3 Report.

111 However, I observe from a scoping document for the Topic Report a tendency for WEC to screen out hazards, rather than demonstrate how the safety functional performance of a safety component is to be delivered, i.e. treating external hazards as events that can give rise to possible initiating faults common cause failure needs to be addressed, as explained in SAP EHA.1.

3.12.3 Large Aircraft Crash

3.12.3.1 Assessment Criteria

112 Ref. 19 treats terrorist and other malicious acts as external hazards (para. 208). Aircraft impact is considered in SAP EHA.8, but as noted in SAP para. 218 malicious acts are dealt with separately. ND has agreed with the relevant authorities appropriate large aircraft characteristics. ND has further determined assessment criteria. ND has set out its expectation in respect of the design of new nuclear power reactors in respect of malicious aircraft impact. These expectations may differ from those of other nuclear safety regulators.

3.12.3.2 Assessment of WEC's Large Aircraft Considerations

113 During GDA the claims made by the requesting parties on the withstand capability of their designs against a wide range of hazards including accidental and non- accidental aircraft crash and other malicious activity is being undertaken. Demonstration of compliance with UK expectations is required to allow the designs to be considered suitable for deployment in the UK. Ref. 6 shows how AP1000 meets the requirements of NRC, and gives me some assurance in general concerning robustness, although WEC will need to show that the design also meets UK regulatory expectations. This is not to say that a design which is acceptable in one country is necessarily unacceptable in the UK. At a later stage it may be necessary to consider site specific elements of proposals, e.g. relevant to spent fuel storage.

114 Ref. 6 sets out WEC's safety case in respect of the response of the nuclear island to aircraft impact based upon the force time curve provided to WEC by the NRC in July 2007. Ref. 6 states that the passive systems do not require AC electrical power, cooling water or fuel supplies from onsite or offsite sources; an aircraft crash outside of the Nuclear Island would not affect the Passive Safety systems and would not result in spent fuel or core damage. I shall verify with my relevant colleagues that AC power is not required. Ref. 6 then proceeds to demonstrate compliance with the NRC criteria. We have conveyed the UK expectations to WEC, and are awaiting a response for my assessment .

3.13 Loads, Analysis and Modelling

3.13.1 Assessment Criteria

115 It is necessary that the combined effects of design code (or other design methodology), loads, analysis, modelling and construction verification together deliver the required reliability, as anticipated for Design for reliability (SAPs EDR.1 to EDR.4) the SAPs.

116 SAP ECE.6 notes:

- For safety-related structures, load development and a schedule of load combinations within the design basis together with their frequency should be used as the basis for the design against operating, testing and fault conditions.

117 SAP ECE.15 notes:

- 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.

118 SAP paras 294 to 296 continue:

- The method should be assessed to ascertain whether the controlling physical equations have been correctly implemented into computer code, or, in the case of hand calculations, correctly incorporated into the calculational procedures. Calculations should be validated in proportion to where the calculation fits into the overall safety case.
- Validation may need to consider the limits of application of the calculational method, the structural representation in the model, comparison with other calculational methods, the level of quality assurance and user proficiency.
- Calculations of beyond design basis conditions involve the prediction of extreme physical behaviour and the calculational 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.

3.13.2 Assessment of WEC's Loads, Analysis, Modelling Software and Modelling

119 WEC specify the use of ASCE 7-98 (Ref. 43) for loads; this code is not widely used in the UK. WEC's loading schedule may become more evident on receipt of the External Hazards Topic Report. WEC cites ASCE 4-98 (Ref. 42) for analysis; parts of this code (or its more recent version) dealing with analysis are widely used in the UK, but the means by which the seismic hazard is specified may differ from historical practice in the UK and the expectations given in ND TAG (Ref. 25).

120 I have identified that the following analysis software has been used in the civil engineering design of AP1000:

- SASSI
- ANSYS
- DYNA (LS-DYNA in Ref. 6)
- VecTor2

121 I am familiar with the first three, and if they have been demonstrated as having been successfully mounted on the computers on which they have been used in AP1000 design, no further assessment is required.

122 I understand VecTor2 to have been developed by the University of Toronto as a development tool based on the state-of-the-art of reinforced concrete research. I have no previously encountered this software, which WEC has used in the analysis of the

interaction between the nuclear island basemat and the soil for AP1000 deployment on soft sites (Ref. 5). At present I am not clear as to whether VecTor2 has been used as a tool in support of a main analysis using ANSYS, or in a more substantive role in the safety case. If the latter, then I intend to investigate how it has been validated.

123 Some of the finite element meshing in a draft version of Ref. 6 showed abrupt transitions, where there did not appear to be a physical requirement for such a transition. It is possible that these related to the geometric location of internal members, but the I shall look further at mesh.

124 Shear in circular un-stiffened hollow cylinders under lateral load can be under-estimated by a factor of up to 2 depending on how the out-of plane stiffness has been modelled. The Shield Wall is partially stiffened at low level by the floor slabs and structural walls of the Auxiliary Building, and again at roof level by the tension ring beam and roof.

3.14 Control of Contractors

3.14.1 Assessment Criteria

125 WENRA Plant licensing requirement B 3.6 states that:

- The licensee shall maintain, in house, sufficient, and competent staff and resources to specify, set standards manage and evaluate safety work carried out by contractors

126 This, and the related, more detailed ND guidance (Ref. 29) is applicable to Licensees, but by analogy RPs need to have specified standards and acceptance criteria for use by design contractors.

3.14.2 Assessment of WEC's Control of Contractors

127 TQ-AP1000-69 concerned the design methodology for SCS construction and asked WEC:

- As WEC's formal position appears to be that the design is to ACI 349-01, please indicate whereabouts in ACI 349-1 does WEC consider the scope of the code to include steel/concrete sandwich construction?
- Please supply any documents that moderate, augment or supplement the requirements of ACI 349-01 that together comprise your design methodology as implemented by yourselves and your contracted designers.

128 WEC response to TQ-AP1000-69, and its successor TQ-AP1000-143 have been variable concerning what is the design methodology for the SCS modules. The most substantive response is Ref. 15, but this is dated 31 August 2009, post-dating much of the design and indeed some of the civil engineering construction on the lead AP1000 unit at Sanmen in PR China. Design methodology is now the subject of RO-AP1000-041.A1.

129 I understand that civil/structural design has been carried out by a number of contracted designers in various parts of the world, including CBI in the USA, Ansaldo Nucleare in Italy, Toshiba/Shaw (alternatively described as Toshiba-Isogi) in Japan, KOPEC in Korea, and INITEC Energia (now a WEC subsidiary) in Spain. I need to be satisfied as to how WEC has assured itself concerning the work of others in that it may affect nuclear safety. In TQ-AP1000-70 I requested WEC to :

- supply a schedule of quality assurance carried out on the design activities of its civil engineering design contractors;
- supply observations, corrective actions, and preventative actions associated with these audits.

130 In response WEC showed that it had carried out QA audits on Toshiba-Isogo and on Chicago Bridge and Iron (CBI). As far as I am aware, Toshiba-Isogo designed the Turbine Building, which is not safety related. CBI designed the steel containment vessel, which for ND's internal purposes is not a civil structure. I have informed WEC that I intend to carry out design audits at the premises of Ansaldo Nucleare in Italy and INITEC Energia in Spain. I have contracted a TSC to support me with three engineers for these audits, in each case including one native speaker for the country concerned. In my design audit, which is planned for November 2009, at Ansaldo Nucleare I expect to cover the in containment structures, which are of much greater safety significance than the Turbine Building covered by the WEC quality assurance audit of Toshiba-Isogo.

131 I had been concerned that WEC had been unable to supply a design methodology for the SCS modules which would have been made available to its design contractors in advance of the design. This raised concern that WEC has not been controlling its contractors appropriately. I had been concerned that the apparent lack of a pre-ordained design methodology and clear acceptance criteria would make the design audits difficult to evaluate. However, at a late stage (6 October 2009) in writing this report I was made aware of and received such a design methodology for SCS modules, though too late to do other than acknowledge its existence. This allays my concern of an apparent lack of a pre-ordained design methodology and clear acceptance criteria. I have planned design audits, and will use these to determine the compliance of the designs with this design methodology.

3.15 Construction Verification

3.15.1 Assessment Criteria

132 Nuclear safety regulation in the UK places a similar level of importance on construction verification as it does on civil engineering design. This is explicit in Nuclear Site Licence Condition 19 (*'Construction or installation of new plant'*), and implicit in other Nuclear Site Licence Conditions, such as LC 12, 14, 17, 20, 22, 25 and 26. Prior to giving Agreement to the lifting of a Hold-point specified under LC 19 (3) NII frequently carries out an inspection as to the adequacy of the Arrangements made under these Licence Conditions and the effectiveness of their implementation.

133 Furthermore the issue of construction verification is addressed in HSE's Safety assessment Principles for Nuclear Facilities (2006 Edition, Revision 1). In particular the civil engineering principles para. 282 f, g, h and i, para. 285, Principles ECE.16, ECE.17, ECE.18, ECE.19 and para. 297 are applied vigorously. We are currently drafting a Technical Assessment Guide to these SAPs regarding Construction Assurance.

134 The Arrangements under the foresaid Licence Conditions will be a matter for any Nuclear Site Licensee that adopts the AP1000. Noting the statement in Section 3.3.2 of Ref. 1 that the site construction of AP1000 plants will be by a constructor selected by WEC, ND will be discussing licensee responsibility with interested parties.

3.15.2 Assessment of WEC's approach to construction verification

135 Section 3.3.2 of the Ref. 1 makes the statement that *"In the UK civil regulatory framework, there is no explicit requirement for construction verification, this being regarded as part of commissioning".*

136 TQ-AP1000-300 requests WEC to correct its understanding of construction verification in the next issue of the PCSR.

3.16 Decommissioning

3.16.1 Assessment Criteria

137 SAP DC.1 states:

- Facilities should be designed and operated so that they can be safely decommissioned.

138 Ref. 26 gives further guidance:

- Have materials been selected which can be dismantled and disposed of in the safest manner?
- Has the structure been detailed so that it can be easily decontaminated?
- Has the structure been designed and detailed so that it can be safely dismantled?
- Have any specific health and safety control measures been identified for the decommissioning and dismantling stages?

3.16.2 Assessment of WEC's Decommissioning Plans

139 Section 17 of Ref. 1 sets out the approach to decommissioning and end of life aspects. WEC state that compared with similar nuclear power plants, the AP1000 has roughly 50 percent fewer valves, 35 percent fewer pumps, 80 percent less piping, and 80 percent fewer heating, ventilation, and air-conditioning systems. Of civil engineering interest are the following:

- The fuel handling building will be converted into an interim waste storage, decontamination, waste reduction, packaging, and processing area for ILW level waste.
- The use of steel floors and walls to ease decontamination.
- The polar crane structure has sufficient capacity to handle heavy equipment with the addition of a larger capacity hoist module.
- In addition, the polar crane can accommodate the upper assembly of the steam generators between the girders.
- Where practicable floor slabs have been designed to support the weight of equipment during the decommissioning process.

140 WEC appears to be referring in part to the use of steel plates, either as permanent shutters or as part of the SCS modules, in its statement concerning ease of decontamination. Such construction may not be amenable to current means of demolition, but advances in demolition technology can be expected over the next several decades.

141 These plans are considered adequate at this stage in respect of civil engineering provision for decommissioning.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

142 The Safety Assessment Principles have been used as the basis for the GDA Step 3 assessment of civil engineering and external hazards associated with the AP1000 design.

143 At the time of writing I am expecting further documentation related to external hazards, codes and standards, and to safety categorisation.

144 Identifying the most relevant documents for my assessment has been hindered by the apparent absence of a logical hierarchical structure between documents.

145 Some of the civil engineering and external hazard matters arise directly from the concept design and structural form adopted, but the reasons for choosing these options are outside the scope of this assessment.

146 WEC needs to consider whether the layout provides adequate segregation in the context of external hazards and ability to withstand internal hazards.

147 There is a transition both in plan and in elevation between RC and SCS sections of the Shield Wall, which can be expected to have different stiffness properties, and which will cause both transverse and torsional asymmetry and amplification of seismic response. The transition also requires robust detailing between the RC and SCS sections. There is a similar transition in the Auxiliary Building. The details of such transitions are important.

148 The safety categorisation system is based on USA practice and needs further study following receipt of the Safety Categorisation report mentioned above. The assignment of the Radwaste Building as category C-III needs further consideration. WEC itself is reviewing its categorisation and classification of safety systems, and an important report on this is awaited.

149 The currency of superseded standards used in the design of AP1000 should be addressed following receipt of the Codes and Standards report mentioned above.

150 It appears that the lack of an appropriate code for the SCS sandwich modular construction proposed for AP600, and now AP1000, was recognized over a decade ago, but has not been addressed. At present WEC is stating that the design is to ACI 349. I am wary of false comfort being taken from a claim that a design is to a particular code or standard used outside its scope of applicability. Amongst my technical concerns are transverse shear, in plane shear, and the effect of thermal loads on the plate to concrete bond. A significant WEC document concerning the design of the Enhanced Shield Building was received too late to be properly considered in this assessment.

151 I had been concerned that WEC had been unable to supply a design methodology for the SCS modules which would have been made available to its design contractors in advance of the design. This raised concern that WEC has not been controlling its contractors appropriately. However, at a late stage in writing this report I was made aware of and received such a design methodology for SCS modules, though too late to do other than acknowledge its existence.

152 The amount of work required by myself and TSCs in relation to civil engineering design methodology must not be underestimated.

153 WEC states the design conditions applied to the plant and in addition identifies those aspects which will require further consideration of external hazards once a site or sites have been identified. There does not appear to be a consideration of lightning or malicious acts (other than malicious large commercial aircraft) as external hazards. In addition, there is no specific recognition of climate change as a driver for a number of hazards. I am deferring this assessment pending receipt of the External Hazards Topic Report referred to in the second para. above. However, I note a tendency for WEC to screen out hazards, rather than to demonstrate how the safety functional performance of a safety component is to be delivered. Common cause failure needs to be addressed. We have recently conveyed UK expectations regarding resilience against impact from a large commercial aircraft and are awaiting a response.

154 Nuclear safety regulation in the UK places a similar level of importance on construction verification as it does on civil engineering design. I have requested that construction verification is addressed in the next issue of the PCSR.

155 It remains to be shown that the combined effects of design code (or other design methodology), loads, analysis, modelling and construction verification together deliver the required reliability.

156 The plans in the PCSR are considered adequate at this stage in respect of civil engineering provision for decommissioning.

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Annex 1 – Civil Engineering and External Hazards – Status of Regulatory Issues and Observations

RI / RO Identifier	Date Raised	Title	Status	Required timescale (GDA Step 4 / Phase 2)
Regulatory Issues				
None				
Regulatory Observations				
RO-AP1000-041.A1	28 August 2009	Civil Engineering Design Methodology	Open	23 October 2009