# A REGULATORY VIEW OF CONTAINMENT INTEGRITY IN THE UNITED KINGDOM

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**ABSTRACT**

This paper reviews the approach of HM Nuclear Installations Inspectorate (NII) to containment integrity in the United Kingdom (UK). NII is that part of the regulatory authority, the Health and Safety Executive (HSE), which administers the UK's nuclear site licensing system. A major part of the licensing process lies in the assessment of licensees' submissions for new and existing plant. The purpose of this paper is to: briefly review our revised Safety Assessment Principles, describe our assessment and inspection activities on the primary containment building of the Sizewell B PWR which is progressing to full power operation in 1994 and to indicate our views on the possible directions for future research into containment design and performance.

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## 1. INTRODUCTION

At the Second International Conference on Containment Design and Operation NII presented a paper which: explained our role and responsibilities in the licensing of nuclear power plant in the UK; outlined our approach to the assessment of the UK's first PWR at Sizewell B and described our views on the acceptability of existing plant without containment (ref 1). Since then HSE has completely revised its Safety Assessment Principles (SAPs) and published a fundamental document on the Tolerability of Risks from Nuclear Power Stations, NII has assessed Nuclear Electric's Pre Operational Safety Report (POSR) for the Sizewell B PWR and carried out inspections of construction and commissioning activities on site.

The objective of this paper is to briefly review the relevant sections of our SAPs and describe our assessment and inspection activities on the Sizewell B primary containment building, which have been guided by (in addition to HSE's Safety Assessment Principles) international PWR experience and relevant UK experience from the design, construction and operation of prestressed concrete pressure vessels. Contributions from each of these will be discussed in relation to: verification and validation of seismic analysis; analytical prediction of ultimate load behaviour, design validation by model test, quality assurance arrangements for design, construction and commissioning and NII inspection of construction and commissioning activities (including the structural over pressure test). This paper will address how structural integrity of the containment building has been demonstrated; it does not cover the performance of safety systems under accident conditions.

The arrangements for in-service inspection of the containment which provide justification of continued fitness for purpose will also be discussed and an indication of our views on the possible directions for future research into containment design and performance is included.

## 2. LEGISLATIVE BASIS

In the UK no site may be used for the purpose of installing or operating any commercial nuclear installation unless a site licence has been granted by HSE. The NII is that part of HSE which is responsible for administering this licensing function. HSE's powers in this regard derive from the Health and Safety at Work etc. Act 1974 and those parts of the Nuclear Installations Act 1965 which are relevant statutory provisions. Most importantly, these include the power to attach conditions, which are legally binding, to the site licences in the interests of safety.

There are thirty five standard licence conditions currently in use, covering such matters as restrictions on dealing with the site, the reporting of incidents, operating instructions and decommissioning. The licence condition on safety documentation which requires the production of safety cases to justify safety throughout the design, construction, manufacture, commissioning, operation and decommissioning phases of the operations is important in the context of this paper.

Under UK law responsibility for nuclear safety rests with the licensee. The role of NII is to ensure that the appropriate standards are developed, achieved and maintained by the licensee, to ensure the necessary safety precautions are taken and to regulate and monitor the actions of the licensee by means of HSE's powers under the site licence. NII independently reviews and assesses licensees' safety cases to confirm compliance with the licence conditions throughout the plant life. The licensees are free to develop their own safety standards and plant safety cases using appropriate methodologies, provided these are in general conformity with NII's Safety Assessment Principles.

## 3. NII SAFETY ASSESSMENT PRINCIPLES

The process adopted by NII in making decisions on the granting of a site licence requires the safety case and supporting reports to be submitted by the licensee for assessment by NII. The Inspectorate needs to adopt a consistent and uniform approach to the assessment process and to this end it is necessary to provide a framework which can be used as a reference for the technical judgements assessors have to make. The NII Safety Assessment Principles (SAPs) form such a framework. The 1992 publication of the SAPs for Nuclear Plant (ref 2) updates and consolidates earlier publications of separate nuclear power and chemical plant principles. The revision covered the following general objectives:

(a) to implement the experience gained since the first publication;

(b) to ensure a greater consistency with international criteria;

(c) to implement concepts from HSE's Tolerability of Risk Paper (ref 3);

(d) to consolidate revisions made as a result of recommendations from the Sizewell B Inquiry;

(e) to combine power reactor and chemical plant SAPs.

The safety submissions from a licensee for a new installation will show that the design meets their standard, but the Inspectorate assesses the submissions to ensure compliance with the SAPs. The following sections identify some typical principles which are applicable to containment design and analysis.

## 3.1 Safety Categorisation

Safety related structures and plant are categorised according to the potential consequences of failure and should correspond to the safety case produced for the plant. The design must take account of the safety function eg. shielding, containment, resistance to hazards etc. under both normal and fault conditions. The following principle concerns the categorisation of structures and systems.

**P69** All structures, systems and components should be allocated a safety categorisation which takes account of the consequences of their potential failure and of the failure frequency requirements placed on them in the safety analysis. This categorisation should be used to determine the standards to which those items should be constructed.

## 3.2 Containment

Containment systems are provided to control the spread of nuclear matter within the plant and its escape to the environment, in normal operations and fault conditions and under external hazard loadings. These containments often have associated systems such as cooling systems and sprays, which are considered to be part of the containment system. The specific principles provided in the SAPs on containment are additional to the general engineering and safety system principles. Some typical examples are as follows.

**P222** Containment and associated systems should be provided as appropriate for nuclear plant to limit radioactive releases to the environment in normal operations and fault conditions and to protect plant from external hazards.

**P224** Containment boundaries should be defined. The containment should be capable of withstanding the effect of internal and external hazards in accordance with the provisions of principles P119 to P143 so that the safe state of the plant is maintained.

## 3.3 Design Data and Models

There are several principles which cover selection of data for design and the use of analytical models to predict results; these are P86-89 and P175. The main emphasis of these principles is to ensure adequate verification and validation is carried out. P86 and 175 are typical examples.

**P86** Theoretical models should be employed as appropriate in support or confirmation of a design basis or as a means of describing safety related conditions in a plant at any time. Such models should be based on a sound scientific understanding and any necessary assumptions or approximations should demonstrably bias results on the safe side.

**P175** Where analyses have been carried out on civil structures to derive static and dynamic loadings for the design, the methods used should be adequately verified and validated, if possible by model test.

## 3.4 Design Principles

The structural integrity section of the SAPs refers to the use of sound engineering concepts and proven design features, the analysis of potential failure modes, the use of proven materials and the application of high standards of manufacture. Some typical principles are reproduced below. An important aspect of design against internal and external hazards is covered in the last sentence of P147; this is to ensure a level of robustness in design.

**P82** The design should be conservative and follow appropriate national and international codes and standards and the plant should satisfy the requirements of best practicable standards of manufacture, construction, inspection, maintenance and operation, commensurate with both the safety categorisation and with any relevant reliability requirements of its component parts.

**P147** For safety related structures, a schedule of all loading combinations within the design basis, together with their frequency, should be used as the design basis against operating, testing and accident conditions. For more severe loadings, predicted failure modes should be gradual and detectable.

## 3.5 In-service Inspection and Degradation Processes

The arrangements for any in-service inspection should take into account the safety function eg. containment, segregation and resistance to hazards under normal and fault loadings. In addition the inspection arrangements should establish that all relevant degradation and ageing phenomena, eg. natural processes, external stresses, wear and tear etc. have been considered. Typical SAPs covering in-service inspection and degradation are as follows.

**P146** It should be demonstrated that all safety related structures are as defect free as possible, are tolerant to any remaining defects, and that the existence of defects can be established by inspection throughout the operational life.

**P163** Inspection techniques for components and structures should be sufficiently redundant and diverse. Personnel and equipment performance should be validated. The safety categorisation should be taken into account when determining the appropriate level of these measures.

## 4. NII ASSESSMENT OF SIZEWELL B

Our review of the Sizewell B primary containment building has covered assessment of design submissions and the inspection of construction and commissioning activities. The assessment of safety submissions has involved: reviewing important elements of the safety case eg. primary containment design reports, verification and validation of analyses; validation by scale model tests and reviewing a range of technical issues. Assessment and inspection of construction activities has covered manufacture and installation of the prestressing system; and inspection of construction and commissioning activities eg. the structural over pressure test on the containment. The purpose of this section is to briefly describe the approach which we have adopted in our assessment and inspection.

### 4.1 Structural Description

The Sizewell B PWR is based on Westinghouse Electrical Corporation's four loop reactor system which will produce approximately 1200 MW (electrical). This design was based upon Bechtel's generic design as embodied in the SNUPPS plants at Callaway, Missouri and Wolf Creek, Kansas. The reactor and its coolant loops and steam generators are contained within a containment building which is designed to control radioactivity release during normal operation and fault conditions.

The containment structure comprises of a vertical concrete cylinder and hemispherical dome which are attached to a generally flat concrete base slab. A mild steel liner is attached to the inner concrete surface to provide a pressure boundary. The structure has provision for access and penetration of its walls by mechanical and electrical equipment. The cylinder and dome portions are reinforced with a combination of ungrouted prestressing tendons and bonded reinforcement. The base slab is constructed of reinforced concrete.

### 4.2 Validation of Seismic Analysis by Model Tests

As indicated in the previous section, SAPs P86 and 175 ask for analyses to be validated. In the case of seismic loading, validation of analytical models of reinforced concrete structures has generally been carried out by either using other models or known mathematical solutions. Model testing of containment structures under seismic loading has only been carried out to a limited extent. One of the most important scale model tests carried out in recent years has been at Lotung in Taiwan, where a 1/4 scale model of a typical PWR plant was subjected to real earthquakes. This has given analysts and engineers the opportunity to use their analytical methods and modelling techniques to predict structural response and compare their results against those measured.

NII expressed reservations on the extent of validation of soil structure interaction analysis of the Sizewell B PWR and asked the licensee to consider validating their methodologies against the Lotung experiment. This was particularly applicable because the ground conditions were considered to be similar since Sizewell was classified as a "soft" site. The analyses were subsequently carried out using the raw data such as soil properties and real earthquake time histories. The computer programs and modelling assumptions were the same as used for Sizewell. Once the soil properties had been adjusted following forced vibration tests the results from the predictive analyses were found generally to be consistent with actual results.

## 4.3 Ultimate Structural Failure, Analysis and Model Tests

To ensure an adequate safety margin over design pressure in Prestressed Concrete Pressure Vessels (PCPV) the British Standard, BS 4975 (ref 4) requires an ultimate load analysis to be carried out. The objective of the analysis is to show that at ambient temperature the vessel can withstand a pressure substantially greater than 2.5 times design pressure. For PCPVs this has been achieved by either analysis or a combination of analysis and scale model testing. For the PWR containment structure at Sizewell B a scale model was constructed and an analysis carried out to determine the likely failure pressure and mode of the structure. Predictive analyses were also carried out by NII and other interested groups from the UK, France and USA.

The purpose of the predictive analysis was to validate the analytical methodologies used and to establish the failure pressure of the containment. This would also satisfy our SAPs P86 and 175. The pressure test on the model was carried out in July 1989. Results from the test confirmed the target ultimate load pressure was exceeded and therefore the test had fulfilled its requirements. Following this an interpretation of the test results was made to identify the location of failure and review displacements and strain gauge recordings. The data were then made available to those organisations which had carried out predictive analyses for them to establish how the results of their analytical modelling compared.

In general the failure modes identified from the scale model had been predicted, although most organisations recognised the necessity to have reviewed the results from certain areas in more detail. In the model analysed for NII, failure of the base had not been predicted since the analysis was insufficiently detailed in this area. However, on closer inspection and greater refinement the regions of high stress were identified. Since the PWR containment was new technology in the UK we consider there were clear advantages in carrying out this work. These were: greater confidence in the analytical methodologies; confirmation of structural capability and identification of likely failure mechanisms and assurance the containment should meet its design intent.

## 4.4 Quality Assurance Arrangements for Design, Construction and Commissioning

Quality assurance is an essential part of an effective management system. It provides a disciplined approach which ensures that arrangements are in place for carrying out an activity. For Sizewell B additional confidence has been provided by the Independent

Inspection Agency (IIA), a body set up by the licensee, consisting of engineers responsible to a director who was not involved with the Sizewell B project, and including representation from an independent third party insurance agency. The IIA has been responsible for the independent certification of the containment design report and construction activities. Its role has also involved observing licensee audits on design and construction activities and carrying out its own as required.

To achieve their objectives IIA have carried out additional calculations as required and produced their own predictive analyses for the containment model test and the structural overpressure test. Their role in construction activities has included surveillance of material production, the endorsement of fabrication and construction work prior to concrete placement, monitoring concrete placement, witnessing the arrangements for and installation of the stressing tendons within the containment and endorsing commissioning activities eg. the integrated leak rate test (ILRT).

To attain confidence in the role of IIA, NII have held regular meetings with them to discuss progress in assessment and inspection and review any findings arising from their work. This has also involved visits to manufacturers' works and site to inspect work being carried out and to establish the involvement of IIA in the review process. We consider IIA have made an important contribution in providing additional confidence in the design, manufacture, construction and commissioning of the Sizewell B primary containment.

### 4.5 NII Assessment and Inspection

To satisfy ourselves on the adequacy of the design, fabrication, construction and commissioning activities for the Sizewell B containment we have carried out routine assessments and inspections. As mentioned in the previous section NII have made frequent visits to the site to ensure the standards specified in the safety case are being met. This has been achieved by inspection of the work as it progresses, discussing planned and trial works, as well as inspection of drawings, material test results and quality assurance records. Two typical areas where we took particular interest were tendon manufacture and installation and the structural overpressure test (SOT) on the containment.

NII assessment and inspection of the stressing system initially involved assessment of the licensee's arrangements for calibration and installation. This was then followed by inspection of the manufacture and installation activities for the prestressing system which involved witnessing: the manufacture of strand; calibration of equipment for stressing operations; fabrication and installation of tendons and stressing of tendons. Subsequent selected tendon load checks which have been carried out in accordance with the requirements of the specification have confirmed the level of load in the tendons is consistent with design predictions.

Two important commissioning tests were carried out in December 1993 and January 1994. These were; the SOT which was to demonstrate structural integrity at 15% above design pressure and the ILRT which was to demonstrate leak tightness of the pressure boundary at the design basis fault pressure was within code allowables. In view of the significance of the tests NII initially reviewed and commented on the arrangements proposed for carrying out the work and subsequently witnessed the SOT.

Prior to the SOT inspections of the condition of the liner and concrete surface were examined and their condition recorded for comparison with test results. Measurements of containment performance during the SOT were collated by a data acquisition system which collected information from embedded strain and stress gauges, inclinometers and displacement gauges. This information was processed and primary data plotted against predicted results on a computer screen. This enabled the test team to readily identify any areas where inconsistencies were arising. In addition to the collection of data inspections were also carried out on the containment surface and penetrations.

Generally the results measured during the test were in line with predictions. For those areas where results were inconsistent with predictions further analytical work demonstrated the results could be predicted by using more refined modelling techniques. However, the predictive analyses were considered to be conservative. No visible signs of permanent damage to the concrete structure or the liner or its steel closures were identified during or after the test. Therefore assessment of all the data collected during and after the test against the structural performance criteria was considered to be satisfied.

4.6 In-service Inspection

One of the licence conditions for Sizewell B covers in-service inspection (ISI) and is titled, "Examination, maintenance, inspection and testing". The contents of this can be generally summarised as follows:-

"The licensee shall make and implement adequate arrangements for the regular and systematic examination, inspection, maintenance and testing of all plant which may affect safety".

During the last twenty years considerable experience has been gained from the routine inspection of the PCPVs (4 Magnox and 14 Advanced Gas Cooled Reactors) in the UK. Therefore the licensees have incorporated some of the methodologies used in their ISI proposals for of the Sizewell B containment.

The main foundation of the proposals is based on adopting those sections of ASME XI (ref 5) which relate to concrete containment and steel liner inspections respectively. We consider the code provides a positive contribution to demonstrating continued fitness for purpose of the containment and welcome the licensee's approach. In addition to the requirements of ASME XI the ISI proposals require foundation monitoring and inspection of the polar crane corbel. Routine data from embedded strain gauges will also be collected and will be used to support the results of inspections. We consider this important since this is the first PWR containment in the UK and the data will help provide confidence in the technology.

## 5. FUTURE DEVELOPMENTS

The primary function of a containment is to provide the ultimate barrier against a radioactive release to the environment under normal and fault loading conditions. It is therefore important to explore ways of achieving a high confidence in the containment function. This can be achieved in several ways such as: increasing the pressure retaining capability by using stronger concrete and providing more tendons; designing against severe accidents; carrying out model test to better understand performance of the containment and liner and further studies on the performance of penetrations.

Work in many areas is already either progressing or being considered by several organisations in the world. Of particular interest to NII is the scale model experiment at Hualien in Taiwan which is investigating the effects of soil-structure interaction and will enable analysts to validate their analysis methodologies for that type of site. The scale model tests of steel and concrete containments which are jointly sponsored by USNRC and NUPEC of Japan will also enable engineers and analysts to carry out predictive analyses to establish failure modes and pressures. We consider scale model containment tests are important and will continue to participate in predictive analyses whenever possible to increase our knowledge and understanding of containment behaviour.

In Europe, various groupings of vendors and utilities have been coming together in the quest for a "next generation" PWR, for possible construction from about 2000 onwards. In parallel, the regulatory authorities have been reviewing their approach to licensing of new plant designs. As regards the containment function, the view which seems to be emerging from Germany and France, in particular, is that the design goal should be to eliminate large early releases of radioactivity under all accident conditions. This would be achieved through the containment design by: reducing containment leakage; ensuring basemat penetration by a molten core is avoided; reducing the risk of combustible gas mixtures occurring, or ensuring the containment will withstand the ignition of those that do. NII has been involved to some extent in these discussions and our view is that the improvements in safety are always welcome. We are, however, wary of placing excessive burdens on industry which may not be justified by the risks involved. The requirement in the UK, as discussed in reference 3, is that the risk should be reduced to as low as is reasonably practicable. Nevertheless, we consider that such discussions are beneficial to both the regulators and utilities, since they should lead to more effective use of resources and a more consistent approach to regulation.

## 6. CONCLUSION

The design, fabrication, construction and commissioning of the Sizewell B containment has been shown to meet the requirements of the safety case. Additional confidence in the design and construction methodologies has been provided by scale model tests, validation of analytical methods against model tests and pressure testing of the containment structure and the liner to demonstrate structural integrity and liner pressure integrity. The requirements of NII's Safety Assessment Principles are thus considered to have been met.

For the future, we consider further work is needed to increase our understanding and knowledge of containment behaviour under pressure and external hazard loadings. This will be enhanced by collaborative experimental work and predictive analyses to validate the methodologies currently used.

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