HSE

Health and Safety
Executive

Sizewell B nuclear power station

The findings of NII's assessment of British Energy's periodic safety review

Contents

Preface

Under condition 15 attached to the nuclear site licence, Periodic Safety Reviews (PSRs) must be carried out by the licensee of a nuclear power plant. The reviews are complementary to the day-to-day regulatory controls which are applied to nuclear power stations. They provide the opportunity to undertake a comprehensive study of plant safety, taking into account aspects such as its operational history, ageing factors which could lead to deterioration in safety, and the advances in safety standards since the time of construction or the previous review. From this, the safety of future operation of the plant can be evaluated.

The reviews are submitted to the Health and Safety Executive's (HSE's) Nuclear Installations Inspectorate (NII) for consideration and assessment to evaluate whether an adequate level of safety has been achieved. The PSRs for the advanced gas-cooled reactors (AGRs) have been completed to an agreed programme and will be repeated at ten-year intervals. The outcome of the first of the AGR PSRs, for the Hinkley Point 'B' and Hunterston 'B' nuclear power stations, was reported by NII in 1997.[1] This was followed by PSRs for Dungeness 'B' in 1998,[2] Heysham 1 and Hartlepool in 1999[3] and Heysham 2 and Torness in 2001.[4]

This is the final report of the first cycle of PSRs for the fleet of British Energy stations. It is also the report on the first PSR of a pressurised water reactor (PWR) carried out by the licensee and assessed by NII. It describes the current position and background to NII's assessment and our conclusions on the acceptability of continued operation of the station for the next ten years. HSE has previously published reports of its PSR findings in paper form (and for the predecessors of the PSRs, the Long-Term Safety Reviews of the magnox stations). However, as greater use is being made of internet-based reports, the decision has been made to report our findings on HSE's website.

Overall, we are satisfied that the licensee has completed a detailed scrutiny of the safety of the nuclear power station. Improvements which the licensee had initiated in advance of the review have enhanced the safety of the station, bringing the design closer to current standards. The overall outcome of the licensee's reviews, together with the programmes of additional modifications and inspections which have been put in place, provide confidence in the ability of this station to continue to operate safely.

Nevertheless, we have also identified the need for some further work and a programme for this has been agreed with the licensee, the majority of which it intends to complete by December 2006. Subject to the completion of this work, and continuing satisfactory results from the routine monitoring and demonstrations of safety required under the nuclear site licensing arrangements, we are confident that Sizewell B nuclear power station can continue to operate safely at least until September 2015, by which time NII will have assessed a further periodic safety review.

Abbreviations

AGR	advanced gas-cooled reactor
ALARP	as low as reasonably practicable
BE	British Energy
C&I	control and instrumentation
EBS	emergency boration (diverse shutdown) system
ERL	emergency reference level
ESWS	essential services water system
HSE	Health and Safety Executive
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IPSART	International PSA review team
IOF	incredibility of failure
LPSA	living probabilistic safety analysis
NII	Nuclear Installations Inspectorate
NRPB	National Radiological Protection Board
NSAP	nuclear safety assessment principles
ORE	occupational radiation exposure
PPS	primary protection system
PSA	probabilistic safety analysis
PSR	Periodic Safety Review
PWR	pressurised water reactor
RAPFE	radial averaged peak fuel enthalpy
RCCA	rod cluster control assembly
RCS	reactor coolant system
RPV	reactor pressure vessel
SCC	stress corrosion cracking
SNUPPS	Standardised Nuclear Unit Power Plant System
SPS	secondary protection system
SSMSG	Sizewell Shoreline Management Steering Group

Introduction

1 The majority of civil nuclear power reactors built in the UK are gas cooled. The first generation of these is the magnox reactors, of which there are still eight reactors operating at four sites. The other 16 magnox reactors are shut down and are in various stages of decommissioning. The second generation of civil reactors built in the UK are of the advanced gas-cooled reactor (AGR) type and all 14 on seven sites are currently operational. Sizewell B nuclear power station has the UK's only civil pressurised water reactor (PWR) and commenced operation in 1995.

2 Prior to any new nuclear installation being authorised to operate, the licensee must have a valid safety case, which is essentially a written demonstration that the intended operation of the plant will be adequately safe. The safety case therefore needs to confirm that all credible hazards have been identified, appropriate standards have been set and met, adequate safety features are in place, all significant assumptions have been identified, verified and validated, and that all instructions, limits and conditions required to maintain operations within specified margins for safety have been identified.

3 As an installation matures, modifications are made to the plant, ageing effects take place, some components may become obsolete and need replacing and plant operating, maintenance and surveillance procedures may be changed as a result of experience. During all this time the safety case must remain valid. The PSR process is designed to ensure that a thorough and comprehensive review is made of the safety case at regular intervals throughout a nuclear power station's life.

4 PSRs have become a well-established feature in the licensing requirements for nuclear plant, and are intended to be more wide-ranging than a restatement of the safety case. They complement the normal day-to-day operational monitoring of safety, which is further underpinned by thorough inspections and assessment of the condition of the plant during normal maintenance and testing as well as during the planned periodic reactor shutdowns.

5 For background information, an outline of the legislation and licensing system used for the regulation of UK nuclear power plants is given in Annex A.

Objective of the periodic safety reviews

6 It is accepted internationally[5] that the objective of a PSR is to determine, by means of a comprehensive assessment, the extent to which the plant conforms to current international safety standards and practices, whether the plants, processes, management, operations and facilities covered by a safety case are safe, and that ageing and other time-related phenomena will not render them unsafe before the next PSR. Where modern standards are not met, the PSR should assess the significance of the shortfalls, and identify reasonably practicable improvements.

7 To satisfy this objective, the licensee is required to:

- review the total current safety case in order to confirm that it remains adequate, or to update and revalidate it as appropriate to cover the period up to the next PSR. The review should be conducted in the light of modern standards and criteria, changes in technology and knowledge, operating experience

(especially in the period since the last review) and modifications to the plant and its equipment;
- look forward in detail over planned future operation for at least the next ten years to show that there are no foreseeable circumstances that could threaten the ability to maintain safe operation; and
- identify safety issues and deal with them by making appropriate plant improvements or operational changes or justify that no action is needed.

8 It is important to note that although the PSR may conclude that the safety case is adequate for a further ten years, this will be dependent upon continued satisfactory results from routine monitoring by the licensee and regulation by NII. Should any safety-related factor emerge in the interim period that may throw doubt upon the continuing validity of the safety case, we would expect the licensee to resolve the matter to our satisfaction.

Working arrangements

British Energy (BE)

9 The licensee (British Energy) is responsible for carrying out and reporting on the PSR. The licensee has considerable experience of carrying out PSRs for its fleet of AGRs and applied the lessons learnt from these to the Sizewell B PSR. The review was carried out over approximately a two-year period in three overlapping stages:

- an Initial Review to provide early identification of Significant Issues;
- the Main Review to cover operation to April 2001; and
- a final update to cover operation, operational experience feedback and key changes to December 2002.

10 The Initial Review was reported to NII in December 2002. The detailed results of the PSR were reported to NII in December 2003 in a suite of documents consisting of:

- an overview document which provides a summary statement of the adequacy of the nuclear safety case;
- five chapters covering:
  - safety management systems;
  - operations and safety performance;
  - ageing, obsolescence and equipment qualification;
  - safety analysis; and
  - systems, structures and components;
- these five chapters are supported by 30 reference documents that comprise reviews based on:
  - safety analysis;
  - systems, structures and components; and
  - technical disciplines.

11 The PSR documentation was produced by station and headquarters staff, assisted in some cases by the licensee's contractors. All the reports were peer reviewed before being submitted to NII. During the production of the PSR, the licensee identified where further work was necessary and this was set down in a programme. This programme of work has also been sent to NII.

Nuclear Installations Inspectorate (NII)

12 Assessment of the Sizewell B PSR involved a team of approximately 20 nuclear inspectors, whose number and composition varied with time. They worked in accordance with the NII guide for PSRs.[6]

13 For the assessment, the inspectors used the NII's *Safety Assessment Principles*[7] as the standard against which to judge the adequacy of the safety review. Our primary focus for the assessment was based on the requirement that the plant, so far as reasonably practicable, is safe and without risks to health. Importantly, application of the Safety Assessment Principles took into account differences between the original standards to which the reactors were built and the current safety standards. Furthermore, the age of the plant and projected life are important factors to take into account in forming judgments on the reasonable practicability of making safety improvements.

14 In the course of its assessment NII identified requirements for further work over and above that identified by BE. These additional requirements have since been incorporated into BE's work programme. A summary of NII's requirements is given in Annex B.

Description of plant

15 Sizewell B nuclear power station is situated on the Suffolk coast, approximately 40 km north east of Ipswich, near the town of Leiston. The Sizewell B PWR is a four-loop plant and is a development of the US Standardised Nuclear Unit Power Plant System (SNUPPS) design, which was augmented mainly to accommodate UK siting and safety requirements. Changes to the SNUPPS design include:

- two diverse reactor protection systems;
- an emergency boration (diverse shutdown) system (EBS);
- four physically segregated trains of protection and safeguards equipment;
- improved emergency core cooling systems;

16 In the reactor, slightly enriched uranium is used for a controlled nuclear fission reaction to produce heat energy. The fission reaction involves splitting uranium nuclei using tiny particles called neutrons. The uranium nucleus splits into two or more fragments which fly apart. Most of the heat energy produced in the reactor is derived from the kinetic energy of these fragments. Gamma rays are also emitted along with two or three fast neutrons. These neutrons are essential to enable a chain reaction to be sustained. PWRs are so-called thermal reactors in which the neutrons emitted as part of the fission reactions are slowed down (moderated) to increase the chances of them causing further fissions in the uranium. The moderator is water, which also acts as the coolant for taking heat from the reactor.

17 The fuel is in the form of uranium dioxide pellets stacked in thin-walled tubes of zirconium alloy, about 10 mm in diameter and about 4 m long, referred to as fuel rods. These form part of a fuel assembly which comprises a square 17 x 17 array of such fuel rods, guide tubes and a central instrumentation guide sheath, all mounted vertically. Each assembly is held at its ends by top and bottom nozzles and supported at intervals along its length by grids. The reactor core is built up of 193 fuel assemblies and is held in place by the upper and lower core plates and the core baffle, all of which are anchored via internal structures to the reactor pressure vessel.

18 Heat produced in the core is transferred to the water, which is pressurised to maintain it in the liquid phase and to prevent significant boiling. The coolant leaves the core and passes to the steam generators where heat is given up to the secondary side feedwater. This results in the production of steam, which is used to drive the turbo-alternators to generate electricity.

19 The fission reaction is controlled by negative power feedback, control rods and boric acid injection. Negative power feedback is the natural reduction in the rate of the reaction as the temperatures of the fuel and the moderator increase. Control rods contain neutron-absorbing materials and are inserted into or withdrawn from the core in order to control the reaction (in a PWR, the control rods are referred to as rod cluster control assemblies (RCCA)). Boric acid is a neutron absorber and its concentration in the coolant is varied to control the reaction rate.

20 The fragments produced by splitting the uranium nuclei are referred to as fission products, many of which are highly radioactive. It is thus important that these are not allowed to be released in an uncontrolled manner. Multiple barriers made up of physical structures and safety systems provide defence-in-depth against potential releases. Physical barriers include the fuel matrix, the fuel rod cladding (which is effectively a pressurised tube) and the pressure boundary of the reactor coolant system, constructed of high-integrity steel components. Furthermore, a massive steel-lined pre-stressed concrete structure provides containment for the whole of the reactor coolant system (reactor pressure vessel (RPV), reactor coolant pumps, steam generators, pressuriser and pipework). Finally, this primary containment structure is itself surrounded by a secondary containment structure.

21 To preserve the integrity of the physical barriers and containments in fault situations, engineered safeguards or protection systems are built into the design. Moreover, to ensure high levels of reliability of these safety systems, the important principles of redundancy, diversity and segregation are widely applied. It is essential that the plant can be shut down and cooled or controlled with high reliability and effectiveness.

Summary of NII's findings

22 Our principal comments on the Sizewell B PSR are grouped under the following headings:

- Safety management systems;
- Operations and safety performance;
- Ageing and obsolescence and equipment qualification;
- Safety analysis;
- Systems, structures and components; and
- Technical disciplines.

Safety management systems

23 It is widely acknowledged that good safety management is essential for achieving high levels of safety and the promotion of a strong safety culture. This requires comprehensive safety management systems to be in place to deliver appropriate safety leadership and decision making and a capable organisation which has an ability to learn lessons from experience. The safety management systems should include arrangements for:

- establishing safety strategies, policies, plans and standards;

- control of resources and contractor support, including control of organisational change and succession planning;
- self-assessment, quality assurance and continuous improvement;
- record-keeping and regulatory compliance.

24 The Sizewell B PSR showed that appropriate management systems are in place. However, it did not explain how adequate these systems are for managing safety. It is not sufficient for the PSR simply to describe the systems. It needs to be shown how those systems are effective. There was no clear link between the various reviews and audits that had been carried out and the planned actions and improvements. The licensee is required to demonstrate how it has reviewed the effectiveness of its management systems and how identified actions and improvements are being addressed.

Operations and safety performance

25 In general, NII is satisfied with the safety performance at Sizewell B. This is monitored regularly by NII through site inspection activities which include start-up and review meetings. In addition, the licensee reports events to NII as required by arrangements made under a site licence condition. Events which are considered by NII to be particularly significant are discussed in paragraphs 26–30.

26 In 1998 a modification to the wiring of the control systems associated with the main steam and main feed isolation valves introduced a defect which resulted in a degradation of the level of protection against faults. A rigorous system of modification implementation meetings has been introduced and amendments to the modification review process have been carried out to prompt closer review where potential for common mode failure exists.

27 In March 1999, shortly after the reactor was shut down for a refuelling outage, a large quantity of reactor coolant system water was released to the containment building during in-situ testing of a safety relief valve. There were no injuries and no release of radiation outside the containment. The event was investigated by the licensee and independently by NII. As a result, these valves are now removed for testing to a separate test facility. Also, many of the station operating instructions were amended to better aid the operators in their response to alarms.

28 In April 1999, radioactive contamination was detected outside the radiologically controlled area. The cause was established as cleaning of an item of contaminated equipment without the appropriate controls being in place. Although the levels of contamination were small and did not give a significant radiation dose to those involved, the event was treated very seriously. Improvements have since been made to communications procedures and pre-task briefings. Additional contamination monitors have been installed.

29 In May 2001 the reactor was shut down to investigate high accumulations of water in the containment, which was confirmed by analysis to be primary coolant leakage. Although the leak had been suspected as coming from an instrumentation seal, it was discovered to have been escaping from the seal between the RPV and its head. The licensee investigated the event and many lessons were learnt. These led to improvements in Foreign Material Exclusion and actions to take upon discovery of water in the containment.

30 There have been a number of cladding failures in the initial fuel. The affected assemblies were predominantly used in operating cycles 1 to 4 (1995–2000) and are being phased out and replaced by assemblies from a different manufacturer. Since the introduction of the new fuel, the number of cladding failures has reduced.

31 The licensee is required to maintain a record of incidents and this has been considered as part of the safety review. Although technical problems and minor incidents have occurred during operation to date, we are satisfied that the licensee has taken appropriate action by making changes to procedures and modifications to plant. While a satisfactory operational record is not in itself sufficient justification for concluding that these reactors can continue to be safely operated for a further ten years, it is a good indicator and has been used by the licensees to justify some of the plant reliability and performance data.

32 The radiation doses to workers have been regularly monitored and controlled well within statutory limits. The results are discussed in paragraphs 58–62. Overall, the review of operating experience has shown that the reactors have been safely operated and that radiation doses to workers have been well controlled.

Ageing and obsolescence and equipment qualification

33 Sizewell B is in a good position in respect of ageing and equipment qualification of plant in that they were considered at the station design stage. Ageing and equipment qualification are addressed in the station safety case and the necessary procedures and processes to ensure compliance have been implemented. Although obsolescence was not explicitly addressed in the safety case, it is recognised that it will become an increasingly important issue over the next review period. There was a basic framework in place for managing obsolescence, but the recent emphasis on life-cycle management and setting up system health monitoring and asset management should bring improvements. We are in broad agreement with the licensee's conclusion that there are adequate systems in place for managing ageing and obsolescence and equipment qualification.

Safety analysis

Nuclear Safety Principles

34 In the UK, the standards for the review and assessment of safety cases are set by the licensee; it is the duty (among other things) of NII to see that appropriate safety standards are developed, achieved and maintained by the licensee. The Nuclear Safety Principles are the high-level principles which are considered to be applicable as current standards for the PSR. Up until the time of carrying out the PSR, these principles were embodied in the station safety case. However, to facilitate the review process, BE produced a separate stand-alone document similar to the AGR Nuclear Safety Principles.

35 In order to conduct the review against current international standards, a gap analysis was carried out against the most recent International Atomic Energy Agency (IAEA) fundamentals and requirements documents.[8,9,10] This identified that there were some areas of the design and operations requirements which were not fully met. These were included in the scope of the review and, where appropriate, improvements have been initiated. For example, the safety case did not contain a worker risk assessment for doses attributable to accidents (see paragraph 41).

Probabilistic safety analysis

36 A probabilistic safety analysis (PSA) was carried out as part of the design work in support of the application for construction. A second, more thorough, PSA was carried out prior to loading fuel and commencing operation. The third stage was the living PSA (LPSA) that, as its name implies, is kept up to date over the lifetime of the station. Each of the PSAs was carried out at the three internationally recognised levels. In brief, these are:

- Level 1 is based on plant analysis and the results are calculated frequencies of core damage and plant damage states;

- Level 2 is based on containment analysis and derives the frequency of uncontrolled release; and
- Level 3 is a radiological assessment that takes the outputs of the Level 1 and 2 results and calculates the frequencies of individual and societal risk.

37 The review concentrated mostly on the LPSA as it was instituted shortly after operation commenced. It was concluded that the LPSA remains fit for purpose.

38 In recent years, one of the proposed applications for the LPSA at Sizewell B has been in risk-informed management of modifications. In order to confirm that the LPSA model, documentation and processes have the correct attributes to be used in that role, BE requested a review by an International PSA Review Team (IPSART) set up under the auspices of the IAEA. This review was carried out in January 2004 and was observed by a small team of NII assessors. The IPSART review concluded that there were many positive aspects of the LPSA and also identified some areas for additional work, such as enhancing the analysis of reliability data and extending the human reliability analysis. This has been accepted by BE and the work has been added to the overall programme.

Human factors

39 Human factors are recognised as major contributors to overall reliability analysis, so the licensee has considered the role of the operator during both normal operation and credible fault conditions. Detailed task analyses have been undertaken to confirm that operating staff would be able to meet the demands placed on them within the time that is available. Nevertheless, although there are management arrangements in place for the conduct of plant maintenance, there has been no analysis of the potential for human error as a result of carrying out maintenance. Consequently, the licensee is required to carry out a qualitative predictive human error analysis of maintenance activities.

Transient analysis

40 Fault studies are required to show that the reactor stays in a safe state, even when a wide range of credible fault conditions is considered. These were included in the original design studies and the PSR has provided an opportunity for a thorough review. The fault sequences and fault transient analyses have been reviewed against current international practice and remain valid. A review was also undertaken of emerging phenomenological issues arising from international practice and concerns. A possible boron dilution fault, identified from international experiments, was a particularly obscure one, which involves reflux condensation after a certain class of loss-of-coolant fault. The licensee has shown that in the unlikely event of such a fault, there will be adequate mixing of borated and unborated water.

Radiological analysis

41 Radiological analysis is performed to assess the consequences of any release of radioactivity. The methods and data used in the radiological analysis for Sizewell B were reviewed and continue to be valid. However, a comparison with modern standards has shown that an assessment of the individual risk to workers attributable to doses from accidents is not currently included in the station safety case. This is now being rectified. Also in line with modern practice, NII requires the licensee to adopt effective dose for the dose banding of faults rather than emergency reference levels (ERL) of dose.

Hazards

42 The safety case developed for Sizewell B used screening criteria as an aid to judgements on which hazards were to be described as having a negligible effect on the frequency of uncontrolled release. These criteria ranged from consideration of

proximity of the hazard to the site of the failures induced by one hazard being bounded by another of similar effect. For the PSR, each of hazards 'screened in' was considered in relation to any changes that had occurred since the station began operation, including changes to plant and procedures as well as any other developments which might have had an effect. In addition, the review assessed the original hazard selection and screening process to confirm the number of hazards to be reviewed and the scope of the coverage.

43 The review identified coastal erosion as an issue that needed to be addressed. The Sizewell Shoreline Management Steering Group (SSMSG) was set up to provide a review body for matters of coastal significance. The SSMSG oversees the various inspections and surveys which are undertaken. Hence, it is considered that all reasonably practicable measures are being taken to ensure that the risk of flooding from this source is minimised. The use of independent experts and the work of the Steering Group is considered to be a significant strength in maintenance of the safety of the station.

44 NII had an issue regarding the extreme wind hazard because of the change in the applicable code (BS 6399)[11] and the consequent changes to predicted wind pressures. Thus BE is required to provide further justification of the effects on the structural capability of the buildings against extreme wind.

Systems, structures and components

Fuel and core

45 The change of fuel vendor from cycle 5 (2000–02) onwards represented a major change to the safety case. Nevertheless, this change was accompanied by a thorough review of the safety case and provided justification for the new codes and methodologies which are now used in the core design and associated transient analysis.

46 The review also resulted in a revision of the limit on radial averaged peak fuel enthalpy (RAPFE) and a new methodology for demonstrating compliance with it. The RAPFE is an indication of the energy in the fuel and becomes important in high burn-up fuel if there is a fault, such as RCCA ejection, which leads the core to become suddenly more reactive. This could lead to fuel rod damage because the cladding ductility reduces, due to oxidation, as burn-up increases.

Reactor coolant and connected systems

47 BE has taken account of international experience and is planning to replace the RPV head during its refuelling outage in the autumn of 2006. This is because it was discovered in some French reactors in the 1990s that the control rod drive penetrations made from the alloy Inconel 600 were susceptible to stress corrosion cracking (SCC). The Sizewell B control rod drive penetrations are made from Inconel 600 and have been inspected at refuelling outages. While minor cracking has been found, it is not regarded as a serious safety concern because the cracks are small, the rate of crack growth is slow and the cracks will not propagate suddenly. The new head uses Inconel 690, a material that is not readily susceptible to SCC. This issue was being managed prior to undertaking the PSR but is thought to be worthy of mention here.

Engineered safety features

48 The engineered safety features are a collection of systems and structures, the primary function of which is to mitigate the consequences of design-basis faults to maintain core cooling and prevent release of radioactivity to the environment. They consist of the containment system, the emergency core cooling system, the auxiliary feedwater system, the emergency boration system and the emergency charging system. Although the review did not identify anything of major concern, some improvements have been included in BE's programme of follow-up work.

Control and instrumentation and safety systems

49 As might be expected for a modern nuclear installation, the design of Sizewell B included a large number of systems and huge numbers of components for control and instrumentation (C&I). The systems covered by the review are:

- the primary and secondary protection (PPS and SPS) for the reactor and the engineered safety features;
- control rod position monitoring;
- neutron flux and nitrogen-16 gamma detectors;
- special in-containment cabling;
- process and plant parameter sensors associated with the PPS, SPS and special instrumentation;
- reactor trip switchgear;
- flux mapping;
- nuclear sampling;
- reactor vessel level instrumentation;
- core exit temperature measurement;
- loose parts and core vibration monitoring.

50 As a result of the review a number of improvements have been identified by BE. These are mainly to update the safety case and procedures.

51 NII also identified areas for further work, in addition to those of the licensee. One of our concerns was that we were unable to discern where safe shutdown had been covered in the review. BE is required to provide evidence that demonstrates that a comprehensive and rigorous review in the areas of C&I for safe shutdown, system performance, maintenance and equipment reliability has been undertaken. We had other concerns which BE has taken account of in its programme for further work.

Central control and data processing systems

52 Again, as Sizewell B is a relatively modern plant it has a high dependence on electronic data processing and control systems. The systems, structures and components covered are those associated with control rooms (main control room and auxiliary shutdown room), high integrity control systems, process control and distributed control systems, and station automatic controls. Apart from miscellaneous updates to instructions and procedures, there was no further work identified. NII noted the physical degradation of some of the equipment sited in harsh environments and have asked BE to provide clarification on its approach to addressing the physical condition of C&I equipment.

Main and essential electrical systems

53 The review concluded that there were no significant shortfalls identified and much of the electrical equipment can be expected to have a service life in excess of 30 years. Where ageing phenomena are anticipated within the next ten years, such as in capacitors in chargers and inverters, a replacement programme is in hand. Nevertheless, two issues arose where NII needed to have confidence that there will be a satisfactory position for the next ten years. Firstly, there are parts of the station earthing system which are not normally accessible and BE had no plans to inspect them. As the integrity of the earthing system is important for the correct operation of the electrical protection equipment, NII sought and received assurance that the scope of the inspection will be increased. Secondly, in February 2005, a significant defect was discovered in the rotor of one of the four essential diesel generators. Similar but lesser defects were found in another two rotors. Although a safety justification was provided for continued operation, the longer-term strategy was not transparent to NII. BE has now formally declared its medium and long-term strategy for dealing with this issue and NII is content.

Auxiliary systems
54 These systems comprise those for:

- cooling;
- process auxiliaries;
- air and gas;
- heating, ventilating and air-conditioning;
- fire protection; and
- overhead handling.

55 The only areas of concern were the physical condition of the essential services water system (ESWS) and the high level of intrusive maintenance of its heat exchangers. In fact, the ESWS problems had been recognised before the PSR and a number of changes have already been implemented. The remainder of the work will be tracked through the PSR process.

Steam and power conversion systems
56 Although these include the turbine generators, the main condensers and the condensate systems, the review was confined to the safety-related systems, namely the main steam system and the main feedwater system. One issue worthy of mention was the discovery of indications in welds in the main steam pipework during a routine inspection in 2003. A case was made for continued operation based on many factors, including a high degree of defect tolerance and high confidence that the indications were manufacturing defects which had not grown in service. Additionally, inspections will be carried out during refuelling outages. NII is satisfied that the situation is secure for at least the next ten years.

Radioactive waste management
57 BE's review identified two principal areas for further work. There is a need to develop and implement a process route or designated store for the filters used to clean up the fuel storage pond. There is also a need to develop and implement a route for the disposal of contaminated oily filters, sludges and rags. While NII is satisfied that much of the review is satisfactory, there is a requirement for BE to review the radioactive waste safety case against the modern standard of preparing safety cases for nuclear chemical plant and radioactive waste management facilities, and revise it accordingly.

Radiological protection

General
58 Annual statutory dose limits for exposure to ionising radiation arising from sources other than medical and natural background are set at levels which ensure that the risk of harm to any person receiving such doses is low. The current annual statutory dose limit for workers is 20 millisieverts (mSv) and that for the public is set 20 times lower at 1 mSv. For comparison, the average dose received in a year from radiation of natural origin in the UK is around 2.2 mSv,[12] though in some parts of the country it can exceed 5 mSv. There is an overriding statutory duty on employers to restrict the exposure of workers and other people to ionising radiation, so far as is reasonably practicable. Advisory bodies such as the International Commission on Radiological Protection (ICRP), and the National Radiological Protection Board (NRPB) (now part of the Health Protection Agency), monitor and research national and international information on radiation on a continuing basis, and issue advice about keeping doses as low as reasonably achievable. They also issue updated recommendations on maximum doses from time to time, as additional or new information comes to light.

59 The most recent ICRP recommendations were published in 1990[13] and NRPB advised on their application in the UK.[14] ICRP effectively recommended a reduction

of the annual dose limit for workers from 50 mSv to 20 mSv, and that for members of the public, from 5 mSv to 1 mSv. In 1992, these recommended limits were incorporated into NII's Safety Assessment Principles.[6] Subsequently, the UK government updated the Ionising Radiations Regulations 1985 to put into effect the 1996 revised Euratom Basic Safety Standards Directive incorporating the revised limits. The new Ionising Radiation Regulations 1999[15] specify the dose limits that have legal force in the UK.

Doses to on-site workers

60 Individual radiation doses to classified workers at Sizewell B continue to be controlled to levels averaging around 0.5 mSv per year. This is well below the current statutory limit and the limit recommended by ICRP and compares favourably with worldwide experience. The majority of occupational radiation exposure (ORE) is incurred from work during outages and arises primarily from activated corrosion products (crud) produced in the reactor coolant. Some of these products plate out on the internal surfaces of the reactor coolant system and are removed chemically at the start of each outage. Particles also drop out of suspension in regions of low turbulence and accumulate in dead spaces where they are not so easily removed (ie crud traps). NII requires the licensee to develop a long-term structured approach for the control of this source of radiation and other radiation hot spots in the plant.

Doses to the public

61 In order to assess the exposure of members of the public to direct radiation from the site, the licensees monitor radiation levels at the perimeter of the Sizewell B site. The licensee has reported the annual dose to the public from direct radiation to be less than 0.025 mSv. This is well below the statutory limit of 1 mSv per year.

62 Under the terms of its discharge authorisations, the licensee measures liquid and gaseous discharges and monitors the environment in the vicinity of the sites on a regular basis. The environment and food standard agencies check the results of these monitoring programmes. These monitoring programmes confirm that the radiation exposure of members of the general public arising from authorised discharges of gaseous and liquid radioactive waste remains very low.

Fuel storage and handling systems

63 Irradiated fuel assemblies are stored vertically in racks in a region of fuel storage pond where the potential storage density has been increased from that in the original design. Currently, only half of the storage capacity can be used because of NII's concern about the adequacy of administrative controls to prevent misloading. BE is presently considering options for engineered solutions to allow the full storage potential to be realised. The proposal on the way forward is to be presented at the end of 2006.

Civil works and structures

64 This is an extensive topic area of systems, structures and components that has been comprehensively reviewed by the licensee. As a result of the review, improvements have been identified and added to the programme of further work. In addition, NII requires BE to provide justification of the prestressed concrete containment structural integrity case, given the predicted confidence levels on the prestressing over the next ten-year period. BE has accepted this and is confident that the latest measurements of tendon loads will provide adequate justification.

Technical disciplines

65 The discipline-based reviews act as major supporting references to the main review and address such things as changes to design codes and relevant good

practice. They identify the major differences that may have an impact on the safety case, evaluate those differences and establish the required actions where necessary to address any resulting issues. The discipline-based reviews cover the following aspects:

- structural integrity;
- chemistry;
- steam generators;
- mechanical plant;
- equipment qualification;
- electrical plant;
- control and instrumentation, safety and computing systems;
- civil works and structures;
- in-service inspection and testing;
- emergency planning;
- external experience and development;
- plant manuals;
- technical specifications.

66 For the most part, NII viewed these documents as being satisfactory and had no issues regarding their content. Nevertheless, there were three technical discipline reviews where NII assessment raised concerns.

Structural integrity
67 It was not clear from the documents referenced for the procedure for assessing the effects on reactor components, whether the bounding locations were still valid. Therefore BE is required to update the procedure for assessing the effect of reactor trips on the IOF components.

Chemistry
68 The importance of chemistry in preserving fuel pin integrity, minimising radioactive waste arisings and minimising operator doses, should be recognised by giving the chemistry technical standards the appropriate status within the hierarchy of the Sizewell B safety documentation.

Control and instrumentation, safety and computing systems
69 BE is required to provide evidence to demonstrate that a rigorous C&I review in the areas of comparison to modern standards, software tools, events/operational feedback, key skills and obsolescence has been undertaken.

Conclusions

70 We conclude that the licensee has conducted a wide-ranging and comprehensive Periodic Safety Review of Sizewell B power station. BE's programme of PSR follow-up work involving modifications, procedural changes, inspections and further analysis will reinforce the safety case for longer-term operation.

71 Nevertheless, as a result of our assessment of the PSR, we have identified some further areas where we require additional improvements in the licensee's safety cases. A programme of actions has been agreed which includes additional analysis, inspection and modifications. Responses to some of these requirements have already been received from the licensee and these are being assessed. The licensee has given NII a commitment to complete the majority of the remaining work by December 2006. Of those few items which will not be complete by then,

NII judges that continued operation will not be affected and that the risks remain as low as reasonably practicable (ALARP). The NII requirements for follow-up work are summarised in Annex B. We require the licensees to report on all ongoing work at regular progress meetings and at the start-up meetings during periodic shutdowns.

72 Provided that the agreed programmes of further analyses, improvements and inspections referred to in paragraphs 70 and 71 above give satisfactory results, NII expects the Sizewell B power station to be able to operate safely until the next Periodic Safety Review. Our conclusion is, of course, subject to the continuing satisfactory results from inspections and justifications of safe operation which are required under the current licensing arrangements.

Annex A: Statutory position for regulation of UK nuclear power plants

Legislation

1 The main legislation governing the safety of nuclear installations is the Health and Safety at Work etc Act 1974 and associated relevant statutory provisions of the Nuclear Installations Act 1965.[16,17] Under these Acts, no site may be used for the installation or operation of any commercial nuclear installation unless a nuclear site licence has been granted to a corporate body by HSE, and is for the time being in force. NII is that part of HSE responsible for administering this licensing function.

2 The Health and Safety at Work etc Act 1974 places a general duty on employers to ensure, so far as is reasonably practicable, the health, safety and welfare of all their employees and also to conduct their undertaking in such a way as to ensure, so far as is reasonably practicable, that people not in their employment who may be affected thereby are not exposed to risks to their health and safety. The radiological protection requirements for the workforce and the public are covered by the Ionising Radiations Regulations 1999[15] made under the Health and Safety at Work etc Act 1974.

3 The Nuclear Installations Act places an absolute duty upon the licensee to ensure that no injury to persons or damage to property is caused from ionising radiation arising from the site. Furthermore, the licensee is responsible under the Act for the safe design and operation of its plant and to ensure the health and safety of its employees and the public.

4 It is the duty of NII to see that appropriate safety standards are developed, achieved and maintained by the licensee, to seek to ensure that the necessary safety precautions are taken and to monitor and regulate the safety of the plant by means of its powers under the licence and relevant regulations.

Licensing system

5 The legislation empowers NII, on behalf of HSE, to issue the licence for a nuclear power station and to attach appropriate conditions in the interests of safety. The Sizewell B site licence has 36 standard conditions attached to it concerning the safety of the plant's operation, maintenance and inspection requirements. One of the conditions attached to the site licence relates to periodic reviews and reassessment of safety, which is the subject of this report.

Annex B: NII requirements for follow-up work

1 BE has reported its Periodic Safety Review for operation of Sizewell B up to 20 years. The PSR is reported in a series of 36 reports covering a number of safety-related subjects, together with an overall summary report. NII's assessment has examined these PSR submissions and many have been found to be acceptable. However, other submissions, or the recommendations arising from them, contain shortfalls and we have identified additional requirements for further work.

2 A current summary of the main requirements for ongoing work is provided below. The licensee is committed to completing most of the remaining work by December 2006. Of those few items which will not be complete by then, NII judges that continued operation will not be affected and that the risks remain ALARP. All the follow-up work will be progressed to a satisfactory conclusion as part of NII's normal regulatory duties conducted under the site licensing arrangements.

Licensee's improvement programme

3 The licensee has identified areas where further safety analyses, modifications or changes in procedures may be required and these are listed in their overall programme. The licensee has already begun implementing this programme of improvements and, while currently ongoing, much work has been completed. We have agreed this programme with the licensee such that the balance of work outstanding will be completed as part of their own PSR process by December 2006, except for a small number of items, which it is judged to be ALARP to complete on a longer timescale.

Safety management systems (see paragraphs 23–24)

4 Carry out further work to demonstrate how the effectiveness of management systems has been reviewed and, where identified, actions are being addressed.

Nuclear Safety Assessment Principles (NSAP) (see paragraphs 34–35)

5 Give consideration to incorporating NSAPs into its normal process for assessing safety case changes.

PSA (see paragraphs 36–38)

6 BE is required to provide a programme of work for modifying the 'living' probabilistic safety assessment (LPSA).

Human factors (see paragraph 39)

7 Carry out a qualitative predictive human error analysis of maintenance activities, according to the scope of work used for such analyses on the AGRs as part of their PSRs.

Radiological analysis (see paragraph 41)

8 BE is required to adopt effective dose for the dose banding of faults.

Hazards (see paragraphs 42–44)

9 Provide further justification of the effects on the structural capability of the buildings against extreme wind, given the change in the applicable design code.

Control and instrumentation (C&I) and safety systems (see paragraphs 49–51)

10 Provide evidence to demonstrate that a comprehensive and rigorous C&I review has been undertaken in the areas of C&I for safe shutdown, system performance, maintenance and equipment reliability.

Central control and data processing systems (see paragraph 52)

11 Provide clarification on the approach to addressing the physical condition of C&I equipment.

Radioactive waste management (see paragraph 57)

12 Review the radioactive waste safety case against the modern standard.

Radiological protection (see paragraphs 58–62)

13 Develop a long-term structured approach, with a programme, for management of crud traps and radiation hot spots.

Civil works and structures (see paragraph 64)

14 Provide justification of the prestressed concrete containment structural integrity case given the predicted confidence levels on the prestressing over the next ten-year period.

Structural integrity (see paragraph 67)

15 Update the procedure for assessing the effect of reactor trips on the incredibility of failure (IOF) components.

Chemistry (see paragraph 68)

16 Review the status, within the hierarchy of the Sizewell B safety documentation, of the chemistry technical standards.

C&I, computing and safety systems (see paragraph 69)

17 Provide evidence to demonstrate that a comprehensive and rigorous C&I review in the areas of comparison to modern standards, software tools, events/operational feedback, key skills and obsolescence has been undertaken.

References

1 *Hinkley Point 'B' and Hunterston 'B' Nuclear Power Stations. The findings of NII's assessment of Nuclear Electric's and Scottish Nuclear's periodic safety reviews* NUC 10 HSE Books 1997 (out of print)

2 *Dungeness B Nuclear Power Station. The findings of NII's assessment of Nuclear Electric's periodic safety review* NUC 14 HSE Books 1998 (out of print)

3 *Heysham 1 and Hartlepool Nuclear Power Stations. The findings of NII's assessment of British Energy's periodic safety review* NUC 16 HSE Books 1999

4 *Heysham 2 and Torness Nuclear Power Stations. The findings of NII's assessment of British Energy's periodic safety review* HSE 2001 (out of print)

5 *IAEA Safety Guide No NS-G-2.10. Periodic Safety Review of Nuclear Power Plants* IAEA August 2003 ISBN 920 108503 6

6 *NSD Technical Assessment Guide T/AST/050 Periodic Safety Reviews Issue 3* April 2004 (www.hse.gov.uk/foi/internalops/nsd/tech_asst_guides/tast050.pdf)

7 *Safety Assessment Principles for Nuclear Plants* HSE Books 1992 ISBN 0 11 882043 5

8 *IAEA Safety Series No 110. The Safety of Nuclear Installations* IAEA July 1993 ISBN 920 101893 2

9 *IAEA Safety Standards Series NS–R-1, Safety of Nuclear power Plants: Design* IAEA October 2000 ISBN 920 101900 9

10 *IAEA Safety Standards Series NS–R-2, Safety of Nuclear power Plants: Operation* IAEA October 2000 ISBN 920 100700 0

11 BS 6399-2: 1997 *Loading for buildings. Code of practice for wind loads* British Standards Institution ISBN 0 580 27447 0

12 *Radioactivity in Food and the Environment 2003 RIFE – 9* Centre for Environment, Fisheries and Aquaculture Science 2004 ISSN 1365 6414

13 *1990 Recommendations of the International Commission on Radiological Protection* publication 60 ICRP 1991 ISBN 008 0411444

14 NRPB report *Board statement on the 1990 recommendations of the ICRP* Documents of the NRPB 1993 Vol. 4 (No 1) ISBN 0 85 9513602

15 *Ionising Radiations Regulations 1999* SI 1999/3232 The Stationery Office 1999 ISBN 0 11 085614 7

16 *Health and Safety at Work etc Act 1974 Ch. 37* The Stationery Office 1974 ISBN 0 10 543774 3

17 *Nuclear Installations Act 1965 (as amended) Ch. 57* The Stationery Office 1965 ISBN 0 10 850216 3

Glossary of terms

burn-up	The fraction or percentage of atoms in a reactor fuel that has undergone fission. Usually given as the total amount of heat released per unit mass of fuel and expressed in megawatt-days per tonne or gigawatt-days per tonne
containment	In power reactors, the containment is a structure other than a reactor coolant circuit boundary, which is or can be sealed for the purpose of containing radioactive releases under normal and fault conditions, together with the systems provided to maintain the adequacy of the containment function
diversity	Dissimilar means of achieving the same objective, usually by the use of different methods, components, materials etc in redundant safety systems to minimise the probability of simultaneous failure from the same cause.
dose	A general term for a measure of exposure to ionising radiation. If unqualified, it should be taken to mean the sum of the effective dose from external radiation and the committed effective dose from intakes of radionuclides
effective dose	A quantity derived from equivalent dose to represent the combination of doses to different tissues in a way that is likely to correlate well with the total of the stochastic effects. It is the sum of the weighted equivalent doses in all tissues and organs of the body, where the weighting represents the relative contribution of the organ or tissue to the total detriment due to the stochastic effects resulting from uniform whole body irradiation
equipment	A formal process to demonstrate that the equipment will meet the system performance
qualification	requirements in normal operation and specified accident conditions
equivalent dose	The absorbed dose averaged over a tissue or organ and weighted by a factor depending on the type and energy of the radiation
fault	Any unplanned departure from the specified mode of operation of a system or component due to a malfunction or defect within the system or component or due to external influences or personnel error
hazard	An internal or external event with the potential to cause equipment damage or failure in the plant
redundancy	Provision of alternative (identical or diverse) elements or systems, so that anyone can perform the required function regardless of the state of operation or failure of any other
reliability	The probability that a component, subsystem or system will perform in the manner required over the time period of interest and in the environment and operating conditions specified

risk	The likelihood of a specified undesired event occurring within a specified period (usually a year) or in specified circumstances
safety culture	An organisational environment which at all levels emphasises safety and uses a variety of managerial, supervisory and individual practices and constraints to sustain attention to safety, through an awareness of the risks posed by the plant and of the potential consequences of incorrect actions
sievert	The unit of equivalent dose and its derivatives, eg effective dose and committed effective dose. For normal operational purposes, the millisievert (mSv) is generally used
societal risk	A general term covering the likelihood of undesired events which affect society as a whole, such as specified numbers of deaths or injuries, numbers of people evacuated, land contamination, economic losses and general social disruption. The particular events must be specified for the term to acquire a specific meaning and to be quantified

Further information

HSE priced and free publications are available by mail order from HSE Books, PO Box 1999, Sudbury, Suffolk CO10 2WA Tel: 01787 881165 Fax: 01787 313995 Website: www.hsebooks.co.uk (HSE priced publications are also available from bookshops and free leaflets can be downloaded from HSE's website: www.hse.gov.uk.)

British Standards are available from BSI Customer Services, 389 Chiswick High Road, London W4 4AL Tel: 020 8996 9001 Fax: 020 8996 7001 e-mail: cservices@bsi-global.com Website: www.bsi-global.com

The Stationery Office publications are available from The Stationery Office, PO Box 29, Norwich NR3 1GN Tel: 0870 600 5522 Fax: 0870 600 5533 e-mail: customer.services@tso.co.uk Website: www.tso.co.uk (They are also available from bookshops.)

For information about health and safety ring HSE's Infoline Tel: 0845 345 0055 Fax: 0845 408 9566 Textphone: 0845 408 9577 e-mail: hse.infoline@natbrit.com or write to HSE Information Services, Caerphilly Business Park, Caerphilly CF83 3GG.

This document is available web only at www.hse.gov.uk/nuclear