NATIONAL NUCLEAR REGULATOR

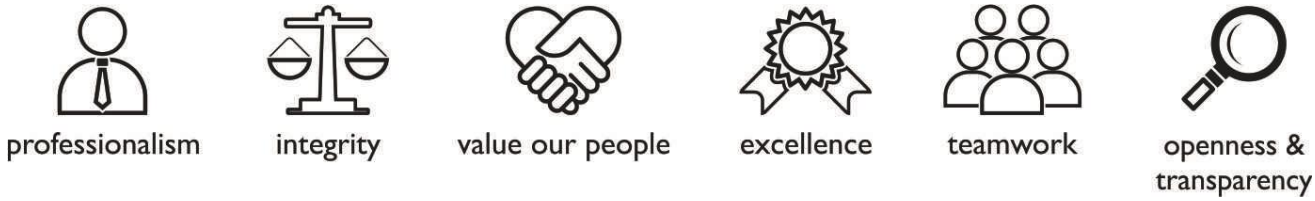
For the protection of persons, property and the environment against nuclear damage

REGULATORY GUIDE

INTERIM GUIDANCE ON THE REGISTRATION OF NUCLEAR POWER PLANT REACTOR OPERATORS

RG-0015

Rev 0



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1 BACKGROUND

Regulations are mandatory and provide specific requirements to be upheld by the authorisation holder and/or an applicant for a nuclear authorisation. Guidance documents are developed to assist authorisation holders and/or an applicant for authorisation in meeting the regulatory requirements. In this respect general guidance documents have to be adhered to by the holder and/or the applicant. Any deviation from regulatory guidance has to be justified in accordance with respective regulations.

The suite of National Nuclear Regulator (NNR) regulations include draft Specific Nuclear Safety Regulations: Nuclear Facilities that are applicable in a graded approach to nuclear facilities being regulated by the NNR.

This document provides guidance on the regulatory requirements as contained in the Specific Nuclear Safety Regulations: Nuclear Facilities relevant to the registration of nuclear power plant reactor operators. Due to the lengthy promulgation process for regulations, and the fact that the guidance provided is based on draft regulations, the Executive has resolved to issue this document as interim guidance.

This document will be revised once the regulations in question have been promulgated and circulated to solicit stakeholder comments in accordance with the Regulator's document development process.

2 PURPOSE

This document provides guidance for the implementation of the requirements as set out in the Specific Nuclear Safety Regulations: Nuclear Facilities on the training, qualification and registration of reactor operators for nuclear power plants or as required by the respective nuclear authorisations.

3 SCOPE

This guidance document clarifies regulatory requirements by providing how-to information, process and procedural guidance related to the registration of reactor operators.

4 TERMS, DEFINITIONS AND ABBREVIATIONS

In this Regulatory Guide (RG) any word or expression to which a meaning has been assigned in the NNRA or the Regulations promulgated in terms of the NNRA, shall have the meaning so assigned. Only additional terms, definitions and abbreviations are provided.

4.1 Terms and Definitions

"**Active status**" means an operator that has been registered with the Regulator and satisfies the requirements for maintaining such registration.

"**Candidate**" means a person applying to the Regulator for examination to obtain a Reactor Operator or Senior Reactor Operator registration.

"**Generic Fundamentals Examination (GFE)**" means an examination, to test theoretical knowledge of individuals who are expected to become reactor operators.

"**Registered Operator**" means an operator in possession of a current Reactor Operator or Senior Reactor Operator registration issued by the Regulator.

"**NPO 0, 9, 1 & 2**" means a Nuclear Plant Operator responsible for the safe operation of the auxiliary plant outside of the main buildings, in the Nuclear Auxiliary Building and the Turbine Halls, respectively.

"**Systematic Approach to Training (SAT)**" means a systematic five-stage process used to produce, deliver and implement a performance-based training and qualification programme. The five stages are:

1. Systematic analysis of the needs, jobs and tasks;
2. Design of the training programme based on the results of the systematic analysis;
3. Development of the materials for training and assessment;
4. Implementation of training and assessment of the learners; and
5. Evaluation and revision of the training based on the performance of trained personnel in the job settings as well as feedback on the training process.

4.2 Abbreviations

IAEA	International Atomic Energy Agency
NNR	National Nuclear Regulator
NNRA	National Nuclear Regulator Act, Act No. 47 of 1999
RG	Regulatory Guide
RO	Reactor Operator
SRO	Senior Reactor Operator
SS	Shift Supervisor
SSRP	Regulations in terms of section 36, read with section 47 of the National Nuclear Regulator Act, 1999 (Act No. 47 of 1999), on Safety Standards and Regulatory Practices

5 REGULATORY FRAMEWORK

5.1 Legal basis

1) In terms of Section 23 of the Act, the Chief Executive Officer may impose (and amend) conditions of authorisation which are necessary to ensure the protection of persons, property and the environment against nuclear damage.
2) Where deemed necessary, current nuclear licenses for the operation of nuclear power plants include conditions on control room reactor operator training and qualification that must be complied with.

5.2 Regulatory standards

1) The NNR has promulgated, in terms of section 36 of the Act, regulations on staffing and qualification. These are given in Regulation R388 on Safety Standards and Regulatory Practices that must be complied with.
2) The implementation of these requirements are further supported by the following documents relating to the reactor operators for nuclear power plants:
    a) LD-1092, “Requirements for Initial Operator Licensing at Koeberg Nuclear Power Station”, Rev 1;
    b) LG-1022, “A Guide to the Requirements for Initial Operator Licensing at Koeberg Nuclear Power Station”, Rev 1; and
    c) LG-1023, “A Guide to the Technical Knowledge Requirements for Candidates for, and Holders of, RO and SRO Licences at Koeberg Nuclear Power Station”, Rev 0.
3) The regulations are being revised and will be superseded by revised General Nuclear Safety Regulations and Specific Nuclear Safety Regulations: Nuclear Facilities.
4) Section 8 (14) of the Specific Nuclear Safety Regulations: Nuclear Facilities contains requirements on training and qualification of reactor operators for nuclear facilities in general with section 8 (14)(o) detailing specific requirements for authorisation holders of nuclear power plants.
5) These requirements will come into effect with the promulgation of the new and revised regulations and must be complied with.
6) This RG-0015 will supersede the regulatory documents listed in 2) above.

6 GENERAL CONSIDERATIONS

1) The following positions are considered by the Regulator to be occupied by a Registered Reactor or Senior Reactor Operator:
    a) Shift Manager [Registered Senior Reactor Operator];
    b) Senior Shift Supervisor [Registered Senior Reactor Operator];
    c) Shift Supervisor (Primary) [Registered Reactor Operator]; and
    d) Shift Supervisor (Secondary) [Registered Reactor Operator].

2) The person who performs the Critical Safety Function monitoring, as required by the Functional Restoration Procedures, should be a Registered RO or SRO who does not fill any of the operator positions in the “Minimum Shift Composition”.

3) The SRO that performs the Emergency Controller function on shift should have passed the Emergency Plan portion of the job performance measure test.

4) The authorisation holder should ensure that the initial operator training programme is continually evaluated and updated. Examples of sources of information that should be considered as part of the evaluation process are:

   a) Feedback from plant experience, nationally and internationally;

   b) Reports from plant inspections and evaluations;

   c) Plant modifications and changes in procedures;

   d) Feedback from job supervisors;

   e) Feedback from in-plant experiences of personnel after completing the course;

   f) Feedback from trainees after the training has been completed; and

   g) Feedback from training instructors or the Regulator.

5) Once the information has been collected, the authorisation holder should perform a review of the information to assess the impact on the training programme and the necessity, if any, for alteration of the programme. The authorisation holder should have standards in place to ensure the uniformity of this process.

6) The authorisation holder should provide for Nuclear Safety and Security cultures to coexist and to reinforce each other due to the common objective of limiting risk of radiation or nuclear damage.

7) For any new nuclear power plant with significant technological differences, the Regulator should be consulted prior to continuation with the training programme.

7 PREPARATION AND TRAINING OF REACTOR OPERATOR CANDIDATES

7.1 Reactor Operator Training Concept

1) All Reactor and Senior Reactor Operators should be registered with the NNR. The process as depicted in Appendix 1 is based on the following:

   a) Candidate meeting the minimum entry requirements prior to start of training;

   b) Candidate successfully completing the mandatory training;

   c) Candidate successfully completing the registration examination; and

   d) Candidate applies to Regulator for registration.

2) Once a candidate has received registration the process of re-registration should be followed to maintain active registration.

7.2 Generic Fundamentals Programme

1) The programme should prepare and allow personnel to become qualified in terms of a minimum standard of theoretical technical knowledge which is applicable to a nuclear power plant.
2) Successful completion of this programme should provide assurance that an acceptable understanding of theoretical concepts has been achieved prior to entering the training programme for RO.
3) The programme should cover as a minimum the topics listed in Appendix 2.
4) The authorisation holder should inform the Regulator of the individuals who have successfully completed the GFE.
5) Successful completion of the examination should be a prerequisite for continuing with the initial training programme for RO.

7.3 Initial Reactor Operator Training Programme

1) The initial training programme should be designed to permit trainees to be trained on the knowledge, skills and abilities needed to perform the duties of reactor operators.
2) The knowledge, skills and abilities should be identified, in part, from learning objectives derived from a systematic analysis of operator duties and from information in the safety case, problem notifications and operating procedures.
3) The initial training programme should cover as a minimum the topics listed in Appendix 4.
4) The authorisation holder should provide the candidates for SRO training in the areas of teamwork and management skills.
5) The authorisation holder should implement an assessment strategy approved by the Regulator, to assess the performance of the team and individual skills and competencies, and have the controls in place to perform an evaluation of training effectiveness.
6) The use of a recognised international standard (e.g. NUREG-1021) for the preparation and conduct of the examination is recommended.
7) The use and alignment to any standard is subject to Regulatory approval.

8 INITIAL REACTOR OPERATOR REGISTRATION EXAMINATIONS

8.1 General

1) The registration examination should consist of three categories, viz. written, simulator and job performance measures (plant walk-through), and should be structured to provide the required assurance that candidates are capable of effectively discharging their responsibilities in terms of nuclear safety in order to protect the public and the environment.
2) A candidate for a SRO registration should be examined to a higher standard than a candidate for RO registration, especially in the areas of integrated plant operation, plant transients, core thermal hydraulics, mitigating core damage and the protection of the public and environment.
3) The SRO should be expected to have performed all tasks, should possess the knowledge, skills and abilities required for a RO and should have obtained sufficient proficiency in these skills to

supervise the control room operators adequately and manage overall plant operations competently.

4) The SRO candidate should be examined as a “System Manager”, i.e. he should be thinking in terms of concepts such as subcooling and heat sink while the RO candidate should be examined as a “System Maintainer”, i.e. he should be thinking in terms of data inputs and reactions to that data.

5) RO and SRO candidates should fulfil security clearance and associated vetting in accordance to the established nuclear security programme.

8.2 Minimum Prerequisites for Reactor and Senior Reactor Candidates

1) RO candidates should meet the following minimum requirements:
   a) Grade 12 with maths and science;
   b) Have been active in the (NPO 0, NPO 9, NPO 1/2 and waste treatment) position for at least six months;
   c) Successfully completed training and qualified as Appointed Person on Plant Safety Regulations in terms of the Occupational Health and Safety Act; and
   d) Participated in at least one unit start-up and shutdown in either NPO 9 or NPO 1/2 positions.

2) SRO candidates should meet the following minimum requirements:
   a) Be registered as an active RO;
   b) At least two years’ experience as an active RO, of which at least six months are as an active SS9/0;
   c) Participated in at least one outage as an active RO;
   d) Successfully completed training, and qualified as Appointed Operator on High Voltage Regulations in terms of the Occupational Health and Safety Act; and
   e) Successfully completed training and qualified as Appointed Person on Plant Safety Regulations in terms of the Occupational Health and Safety Act.

3) Additional requirements for RO and SRO candidates prior to the final application for registration:
   a) The GFE has been completed by RO and SRO candidates;
   b) RO candidates have successfully completed the training and are qualified as authorised persons (High Voltage Regulations);
   c) RO and SRO candidates have been trained in accordance with approved SAT-based programmes and have passed the final programme evaluations; and
   d) SRO candidates have been successfully trained in behavioural skills (teamwork and man-management) in accordance with approved programmes.

4) If any of the prerequisite or minimum requirements are not fully met, the authorisation holder should provide justification and obtain formal Regulator approval prior to continuation of the registration examination process.

8.3 Examination

1) In accordance with the Specific Nuclear Safety Regulations: Nuclear Facilities [4], the authorisation holder must notify the Regulator at least six months in advance of the conduct of the registration examination for operators.
2) A table with the proposed timeline for the preparation and conduct of the examination is contained in Appendix 3. The timeline may be adjusted with the approval of the Regulator.
3) Such examination programme could include the review and approval by the Regulator of the developed examination material.
4) The number of candidates to be examined at any one time should be managed to ensure that the use of surrogates is minimised.
5) An examination security plan and agreement should be in place during the preparation and administration of examinations. The format and detail should be approved by the Regulator.
6) SRO candidates are assumed to have the abilities of RO candidates as far as panel manipulations are concerned; therefore, they should not normally be examined in that role. However, the Regulator reserves the right to request an examination in the RO position if deemed necessary.
7) The criteria for potential re-examination should be documented in the authorisation holder's programme and standard that is approved by the Regulator.
8) The minimum pass criteria for written and job performance measures should be 80%. The simulator pass criteria should be determined by the criteria in the evaluation standard used which has been approved by the Regulator.

9 REACTOR AND SENIOR REACTOR OPERATOR REGISTRATION

9.1 Application for Registration

1) In accordance with the information required to be submitted by the Specific Nuclear Safety Regulations: Nuclear Facilities [4], the application should contain the following information of the candidate:
   a) Full name;
   b) Home address;
   c) Postal address;
   d) Identification document number (Passport number for foreigners);
   e) Candidate's education, training and certified copies of academic qualifications;
   f) Candidate's current status of medical and psychological fitness;
   g) Candidate's results from the registration examination; and
   h) Declaration by the authorisation holder that the candidate meets all the requirements for registration application.
2) The above information should be submitted to the Regulator in a format as approved by the Regulator.

3) When the information has been reviewed, the authorisation holder will be notified in accordance with the requirements in the Specific Nuclear Safety Regulations: Nuclear Facilities [4] on the outcome of the application.

4) If successful, the candidate will receive a registration number from the Regulator. The registration is valid in accordance with the Specific Nuclear Safety Regulations: Nuclear Facilities [4].

5) The registration stays active as long as the registered operator complies with applicable Regulatory conditions related to:

   a) Maintaining active status;

   b) Fitness for duty;

   c) Medical and psychological status;

   d) Requalification status; and

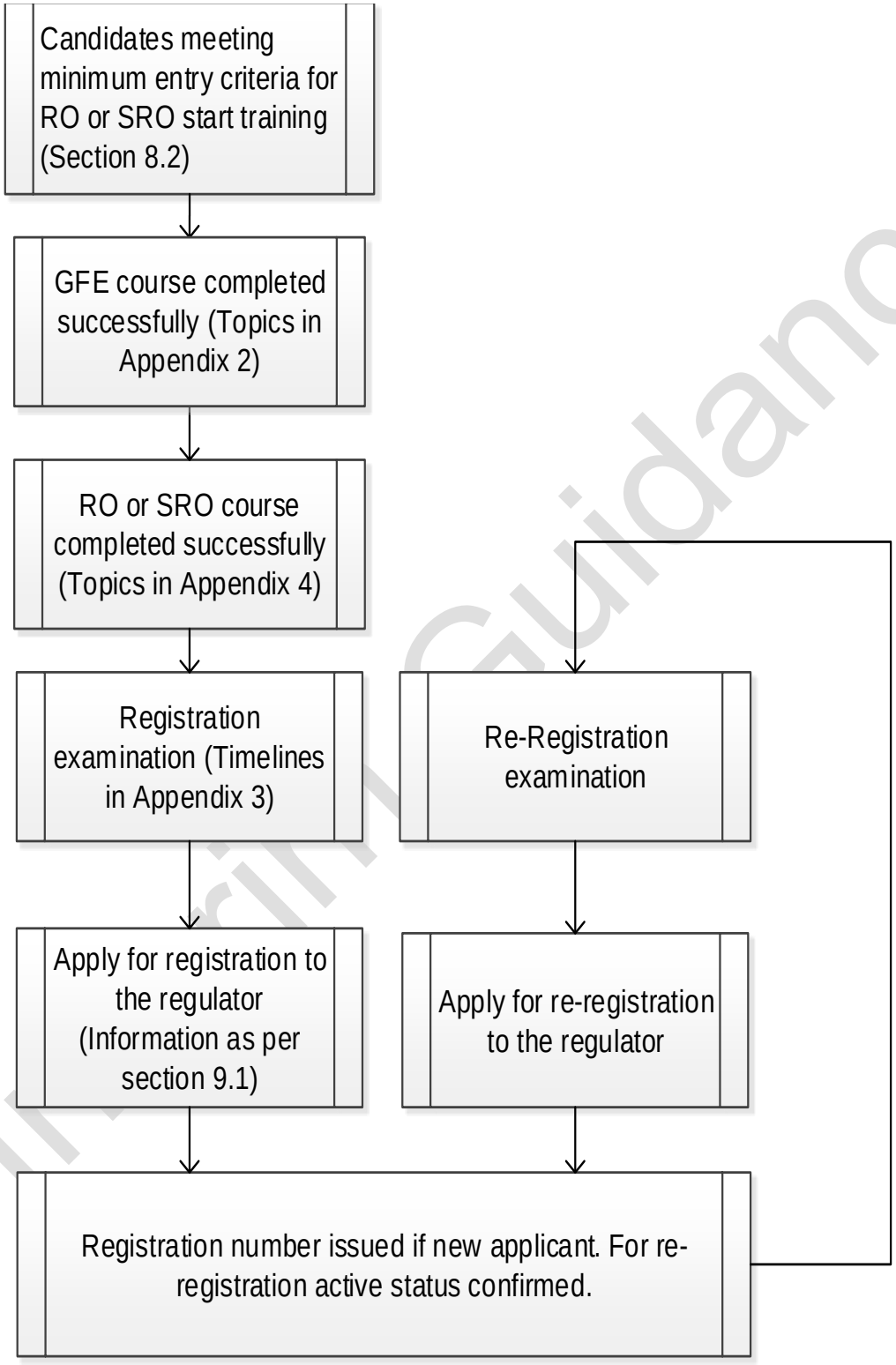
   e) Security clearance as provided by the holder and/or applicant.

10 REFERENCES

The following references were consulted during the compilation of this document:

[1] Act No. 47, 1999, National Nuclear Regulator Act
[2] Regulations in terms of section 36, of the National Nuclear Regulator Act, 1999 (Act No. 47 of 1999), on Safety Standards and Regulatory Practices (GN R388)
[3] General Nuclear Safety Regulations (Section 36 of NNR Act) (2015 revised edition)
[4] Specific Nuclear Safety Regulations: Nuclear Facilities (Section 36 of NNR Act) (2015 edition)

APPENDIX 1: REACTOR OPERATOR REGISTRATION CONCEPT



APPENDIX 2: MINIMUM TOPICS FOR GENERIC FUNDAMENTALS PROGRAMME

1. FUNDAMENTALS OF NUCLEAR PHYSICS

1.1 Quantities, Units and Symbols

- The quantities that are essential in nuclear engineering, including the associated symbols and units.

1.2 Structure of the Atom and Radioactive Decay

- Structure of the atom, nuclear charge and mass number.
- Terms: isotope, isotone, isobar, nuclide, neutron, proton, electron, gamma quantum.
- Types of radiation: α, β, ɤ and n radiation.
- Changes in the nucleus and related energy transfer with respect to α, β, y and n decay.
- Representation of the decay laws on the basis of the nuclide chart and decay chains.

1.3 Interaction of Radiation with Matter

- Interactions of α and β radiation with matter.
- Qualitative statements concerning shielding against α and β radiation.
- Interaction of y radiation with matter (energy transfer, scattered radiation), or neutrons with matter (scattering, capture fission).
- Qualitative statements concerning the shielding against y radiation.
- Neutron sources.
- Qualitative relationship between temperature and neutron kinetic energy.
- Process of nuclear fission; binding energy.
- Fission cross sections and their dependence on the neutron energy.
- Terms: fission product, activation product.
- Breeding and conversion processes.
- Qualitative statements concerning the shielding against neutrons.
- Enumeration of the most important fissile and fertile nuclides.

2. REACTOR PHYSICS

- Chain reaction.
- Explanation of the relationships described in the 6-factor formula and their extension to the real reactor.
- Multiplication factors (type and meaning of).
- Reactivity (relation to multiplication factor), moderator, reflector, coolant (effect, materials).
- Prompt and delayed neutrons (terms, production, meaning of controllability of the reactor).
- Statements concerning the apportionment of delayed neutrons of the most important fissile nuclides.
- Terms: critical, prompt critical; changes of neutron flux density at or near the critical or prompt critical state.
- Term: stable period; qualitative statements concerning reactor period or relative rate of flux change.
- Terms: stationary, transient; transitional behaviour.
- Relationship between the neutron flux density and reactor power.
- Neutron flux measuring methods.
- Impact of changes in the density of the moderator on the neutron flux.
- Qualitative statements concerning the distribution of the neutron flux density over the core and in the proximity of a fuel element and a control rod.

- Dependence of reactivity on fuel temperature, coolant or moderator density (steam voids), boron concentration reactor power, moderator temperature and pressure.
- Dependence of the coefficient of reactivity on burn up and boron concentration.
- Qualitative statements concerning the operating behaviour above and below the critical state and in various power ranges.
- Influence of the poisons (burnable and non-burnable absorbers and the selective way they are used) on the neutron flux density and its distribution.
- Xenon poisoning (term, build-up process via fission products, dependence on neutron flux density and kind of load change, time behaviour, influence on reactivity) and xenon oscillations.
- Possibilities of controlling the reactor:
  - Burnable poisons.
  - Control rods, boron concentration.
- Methods/techniques of core monitoring of the subcritical or critical reactor.
- Neutron start-up source (purpose, effect).
- Reactivity balance (qualitative), shutdown margin, and shutdown reactivity.

3. ENERGY RELEASES AND THERMAL HYDRAULICS

- Properties of water, wet steam, saturated steam, superheated steam; identification of these conditions; handling of h-s, T-s diagrams, throttling, expansion.
- Circuit process in the thermal power plant. Change of state of boiling water as a result of compression or decompression.
- Resistance in pipes and valves. Orifice measurements, operating states of centrifugal pumps, operating limits, cavitation, water hammer.
- Mechanisms of heat transfer. Heat transition from metal to water or steam, from water to steam. Condensation. Heat transfer capabilities of heat exchangers.
- Bulk boiling, nucleate boiling, film boiling.
- Heat conduction in the fuel and heat transfer from the fuel to the coolant (qualitative).
- Terms: critical heat flux, hot spot, minimum critical heat flux ratio, DNB ratio.
- Mechanisms and qualitative division of energy release (generation of heat):
  - In the fuel;
  - In the moderator;
  - In the coolant;
  - In the core internals; and
  - In the shielding;
  - During operation and after shutdown, depending on the type of radiation and as a function of the reactor power during the preceding operating phase.
- Natural circulation (one-phase, two-phase), limits of natural circulation, two-phase energy transportation, heat loss from pressurised vessels or systems (cold, hot), single-phase flow (water or steam), two-phase flow (water and steam).
- Critical pressure ratio during outflow processes, critical rate, nozzle.
- Heat and mass balances in distributed systems (approach).
- Physical behaviour of air-steam mixtures (qualitative). Build-up of H2 concentrations in steam-air mixtures and their ignition limits, methods of prevention of ignition and reduction of H2.

4. RADIOLOGICAL PROTECTION

- Dangers resulting from radiation, objectives of radiological protection.

- Explanation of the terms which are essential for radiological protection such as: activity, specific activity, activity concentration, half-life, effective dose, dose rate, half-value thickness, activation, contamination, incorporation, inhalation, ingestion, submersion.
- Understanding of the mode of functioning, handling and scope of application of radiation measuring instruments and equipment (e.g. ionisation chamber, proportional counter tube, Geiger-Müller tube, scintillation detector, semiconductor detector, neutron detector, film badge, TLD, and pocket dosimeter), for the measurement of doses in radiation fields, or for the measurement of surface contamination.
- Demonstrate an understanding of how the AADQs are derived. Demonstrate an understanding of the Annual Limit on intake.
- Dose limits for occupationally exposed persons in the controlled zone.
- Protective measures to be implemented during the handling of unsealed and sealed radioactive sources.
- Natural radiation exposure (sources, intensity).
- Demonstrate an understanding of dose levels at which deterministic effects manifest.
- Dangers of incorporation of radioactive substances (preventive and subsequent measures, measuring methods).
- Preventive measures against entrainment of contamination (body, clothing, tools, equipment). Decontamination measures, in particular obstinate decontamination of the body.
- First protective measures until the arrival of the Radiation Protection personnel (control measurements, security measures, decontamination of persons).
- Measures and equipment for individual dose monitoring. Time intervals for reviews of individual doses as well as medical radiological protection examinations of persons exposed to radiation.
- Protective measures and behaviour for the minimisation of radiation exposure during maintenance work missions in the restricted access areas (protective effect of distance and working time, shields, protective clothing, and respirators).
- Cooperation with Radiation Protection staff.

5. VALVES

- The function and operation of safety valves.
- The function and operation of relief valves.
- The relationship of valve position to flow rate and back pressure.
- The failed valve positions for different actuators (open, closed, and as is positions; spring loaded valves; hydraulic, pneumatically controlled valves; electric motor-drive valves).
- Equipment protection concerns in the use of valves (protect valve seals, open slowly).
- Manual operation of MOV with motor inoperable.
- Principles of operation and purpose of check valves.
- Operation of valves and verification of position.
- Reason for using globe valves versus gate valves for throttling.

6. SENSORS AND DETECTORS

6.1 Flow

- Characteristics of venturis and orifices.
- Temperature/density compensation requirements.
- Effects of gas or steam on liquid flow rate indications (erroneous reading).
- Modes of failure.
- Operation of a flow DIP cell type flow detector.

6.2 Level
- Temperature/pressure compensation requirements.
- Theory and operation of level detectors.
- Effects of operating environment (pressure and temperature), modes of failure.

6.3 Pressure
- Theory and operation of pressure detectors (bourdon tubes, diaphragms, bellows, forced balance and variable capacitance).
- Effects of operating environment (pressure and temperature).
- Modes of failure.

6.4 Temperature
- Theory and operation of TIC RTD, thermostats.
- Failure modes of TIC and RTD.

6.5 Position Detectors
- Failure modes of reed switches, limit switches, and potentiometers.
- Application of reed switches, magnets, potentiometers, and limit switches.

6.6 Nuclear Instrumentation
- Effects of core voiding on neutron detection.

6.7 Portable and Personal Radiation Detection
- Theory and operation of ion chambers, G-M tube and scintillation detectors.
- Use of portable and personal radiation monitoring instruments.
- Theory and operation of failed fuel detectors.

7. CONTROLLERS AND POSITIONERS

- Function and operation of flow controllers in manual and automatic modes.
- Function and operation of a speed controller.
- Operation of valve controllers in manual and automatic modes.
- Function and operation of pressure and temperature controllers, including pressure and temperature control valves.
- Function and characteristics of valve positioners.
- Function and characteristics of governors and other mechanical controllers.
- Safety precautions with respect to the operation of controllers and positioners.
- Theory of operation of the following types of controllers: electronic, electrical, and pneumatic.
- Effects on operation of controllers due to proportional, integral (reset), derivative (rate), as well as their combinations.
- Function and characteristics of air-operated valves, including failure modes.
- Cautions for placing a valve controller in manual mode.

8. PUMPS

8.1 Centrifugal
- Identification, symptoms, and consequences of cavitation.
- Reasons for venting a centrifugal pump.
- Consequences of air/steam binding.

- Consequences of operating a pump dead headed or for extended times without adequate recirculation.
- Relationships between head, flow, and power as related to pump speed.
- Need for net positive suction head (NPSH); effects of loss of suction.
- Starting current and operating current interpretation.
- Purpose of starting a pump with discharge valve closed.
- Pressure and flow relationship of pumps in parallel.
- Pressure and flow relationship of pumps in series.
- Definition of pump shutoff head.
- "Run out" of a centrifugal pump (definition, indications, causes, effects, and corrective measures).
- Theory of operation of centrifugal pump.
- Use of centrifugal pump characteristic curve and a system characteristic curve to illustrate how the system operating point changes due to system changes.
- Relationship between flow from a pump and suction heads.
- Safety procedures and precautions associated with centrifugal pumps.
- Definition of pump efficiency.
- Explanation of the difference between ideal and real pumping process.

8.2 Positive Displacement

- Relationship between head, flow, speed and power.
- Net positive suction head (NPSH) requirements for a positive displacement pump.
- Consequences of operating a positive displacement pump against a closed flow path.
- Applications and characteristics of positive displacement pumps.
- Reason for starting a positive displacement pump with the discharge valve open.
- Safety procedures and precautions associated with positive displacement pumps.
- Basic operation of positive displacement pumps.
- Theory of operation of positive displacement pumps.
- Characteristic curve for a typical positive displacement pump and the reason for its shape.

8.3 Jet Pumps

- Principles of operation of a worm pump.

9. MOTOR GENERATORS AND TRANSFORMERS

- Indication of a locked rotor.
- Potential consequences of overheating insulation or bearings.
- Causes of excessive current in motors and generators, such as low voltage, overloading, and mechanical binding.
- Relationship between pump motor current (ammeter reading) and the following: pump fluid flow, head, speed, and stator temperature.
- Difference between starting current and operating (running) current in a motor.
- Reason for limiting the number of motor starts in a given time period.
- Electrical units: Volts, Amps, VARs, Watts, Hertz, Impedance and Reactance.
- Consequences of over excitation/under excitation.
- Interrelations of the following: VARs, Watts, Amps, Volts, Power factor angle, load angle.
- Load sharing with parallel generators.
- Motor and generator protective devices.
- Transformer types, ratios and tap changing.
- Power Calculations in three phase circuits.

10. HEAT EXCHANGER AND CONDENSERS

- Start-up/shutdown of a heat exchanger.
- Proper filling of a shell-and-tube heat exchanger.
- Basic heat transfer in a heat exchanger.
- Effects of heat exchanger flow rates that are too high or too low and methods of proper flow adjustment.
- Flow paths for the heat exchanger (counter flow and U-types).
- Components of a heat exchanger (shells, tubes, plates, etc.)
- Control of heat exchanger temperatures.
- Relationship between flow rates and temperatures.
- Definition of thermal shock.
- Principle of operation of condensers.
- Relationship between condenser vacuum and back pressure.
- Effects of tube fouling and tube failure scaling on heat exchanger operation.
- Consequences of heat exchanger tube failure.
- Reasons for non-condensable gas removal.

11. DEMINERALISERS

- Effect of excessive differential pressure on demineraliser performance.
- Effects of channelling in a demineraliser.
- Reason for sampling inlet and outlet of demineraliser.
- Reason for demineraliser temperature and flow limits.
- Principles of demineraliser operation.
- Demineraliser DIP to determine condition of demineraliser resin bed.
- Effects of demineraliser operation on water conductivity.
- Demineraliser characteristics that can cause a change in boron concentration.
- Reasons for bypassing demineralisers.
- Reasons for using mixed-bed demineralisers to process primary water.
- Plant evolutions which can cause crud bursts and the effect on demineralisers.
- Definition of "boron saturated" as it relates to a demineraliser.
- Definition of "lithium saturated" as it relates to a demineraliser.
- Effect of temperature on saturated ion exchangers.

12. BREAKERS AND RELAYS

- Purpose of racking out breakers (de-energise components, associated control and indication circuits).
- Local indication that breaker is open, closed or tripped.
- Loss of control power supply, circuit breaker indicator lights and capability to remotely open and close.
- Operation of various push buttons, switches and handles and the resulting action on breakers.
- Function of thermal overload protection device.
- Interpretation of symbols for breakers, relays and disconnects in a one-line diagram.
- Safety procedures and precautions associated with breakers, including high, medium and low voltage breakers, relays and disconnects.
- Effects of closing breakers with current out of phase, different frequencies, high voltage differential, low current, or too much load.

- Effect of racking out breakers on control and indicating circuits and removal of control power for breaker operation.
- Function, control and precautions associated with disconnects.
- Control room indication of a breaker status.
- Trip indicators for circuit breakers and protective relays.

APPENDIX 3: REGISTRATION EXAMINATION PROCESS TIMELINE

Days from examination start date	Activity
− 180 days	• Notify Regulator of selected candidates for examination. • Notify Regulator of start date of examination. • Establish examination security plan.
− 90 days	• Submit examination outlines to Regulator.
− 30 days	• Submit complete examination package, current medical and psychological status, security agreements and examination schedule to Regulator.
Examination start date	• Start of registration examination.
± 30 days	• Submit individual registration application package to the Regulator.

APPENDIX 4: MINIMUM KNOWLEDGE REQUIREMENTS FOR OPERATORS

1. FUNDAMENTALS OF NUCLEAR PHYSICS

As per Generic Fundamentals Programme in Appendix 2.

2. REACTOR PHYSICS

As per Generic Fundamentals Programme in Appendix 2.

3. ENERGY RELEASES AND THERMAL HYDRAULICS

As per Generic Fundamentals Programme in Appendix 2.

4. RADIOLOGICAL PROTECTION

As per Generic Fundamentals Programme in Appendix 2.

5. STATUTORY BASES

- National Nuclear Regulator Act.
- Basic aims of protection.
- Licensing prerequisites.
- Changes to the plant or of its operation which require a license change.
- Access and authority of inspectors of the Regulator.
- Basic requirements of Requirement Documents.
- Requirements with respect to the responsibilities and authorities of registered operators.

6. OCCUPATIONAL SAFETY

- Behaviour in conformance with accepted occupational safety.
- Statutory bases for job-related occupational safety, and provisions and rules of importance to occupational safety.
- Characteristic dangers and measures for the prevention of accidents.
- Basic measures and procedures for maintenance work (permit to work procedure).
- Measures in the case of personal injuries, particularly those resulting from radiation accidents.
- Fundamentals of fire prevention and firefighting in a nuclear power plant; behaviour during fires; basic features of fire alarms.

7. RADIOLOGICAL PROTECTION STANDARDS

- Major provisions of the standard and their relationship to:
  - Principles of radiological protection.
  - The Senior Authorised Person (RP) and the persons responsible for radiological protection, as well as their positions and duties.
  - Ventilation and plant radiation monitoring systems.
  - Measures to be taken with events that affect nuclear safety.
  - Arrangements for mitigating the consequences of accidents or incidents.
  - Instructions.
  - The display of radiological protection ordinance (e.g. RPCs, zones).

- The protection of air, water and soil.
- Occupational radiation exposure.
- Environmental surveillance.
- Other radiation exposures taken into account.
- Work prohibitions and restrictions.
- The delimitation of controlled zones.
- Local doses measurement in radiological areas.
- Radiological protection supervision.

8. FUNDAMENTALS OF REACTOR ENGINEERING AND REACTOR SAFETY

- Basic layout of a pressurised water reactor.
- Hazards involved in the use of nuclear energy (fissile product inventory, uncontrolled criticality); risk.
- Terms: normal operation, abnormal operation, incidents.
- Safety concept; single and multiple failure concepts, quality assurance.
- Residual heat removal (RHR) during normal operation, RHR following the failure of the main heat sink, RHR during the loss of coolant.
- Basic layout and the function of the barriers against the release of radioactive substances into the plant and the environment.
- Terms: inherent safety, diversity and redundancy, fail-safe principle, energise and de-energise to trip, active fault, passive fault, self-reporting fault (examples).
- Survey of the tasks and of typical modes of functioning of important active and passive safety systems in the pressurised water reactor plant.
- Knowledge of the physical measuring principles of instrumentation.
- Knowledge of the behaviour of measured data indications in the case of faults in the measuring system.
- Basic aspects with which reactor protection measures become necessary.
- Anticipated typical event sequences which may cause danger to:
  - The personnel in the plant;
  - The plant, including damage to the reactor core; and
  - The environment;
  - During normal, abnormal or incident operations.

9. PLANT ENGINEERING

9.1 Buildings and Building Equipment

- Layout and functions of buildings, access, location of systems and components with particular consideration to emergency cooling and residual heat removal; location and function of systems and components operated from the control room.
- Functions to be performed and different modes of functioning of building equipment important to safety (e.g. airlocks, escape doors, fire protection doors, fire alarms and firefighting equipment, smoke exhausts and equipment at the entrance to the controlled zone).
- Arrangements of escape routes, assembly points, fences and surveillance equipment.
- Accessibility of plant areas during all modes of reactor operation.
- Local position of firefighting equipment.

9.2 Reactor Pressure Vessel and Internals

- Functions to be performed, different modes of functioning, arrangement and layout of the major components (e.g. fuel elements, neutron sources, in-core instrumentation, control rods including drives, vessel head, seals and leakage monitoring).

9.3 Reactor Coolant Circuit

- Functions to be performed, different modes of functioning, arrangement and layout of the pressuriser, pressuriser relief tank, steam generators, reactor coolant pumps, safety valves, relief valves, isolation valves; design and operating data.
- Energy sources and heat sinks, energy transportation during power operation, during forced circulation with the reactor shut down, or in natural circulation.
- Interpretation of the measured data for the identification of the operating state, mode of operation, influence of the mode of operation on the reactor coolant circuit and adjacent systems, initiation of corrective actions in the case of malfunctions.

9.4 Reactor Control

- Principle and mode of functioning (control rod control, pressure control, level control, coolant temperature control, power distribution control, power level control).
- Impact of control on the various systems.
- Modes of operation (manual, automatic) and functions (limitation of control, maximum values, interlocks), overriding control functions between reactor control and control of the water/steam circuit (e.g. rated values of power and secondary pressure).

9.5 Limitations of any System

- Functions to be performed, different modes of functioning, checking for operability, activation criteria.

9.6 Control Rod Drive Mechanism

- Functions to be performed and different modes of functioning of control rod drives and the reactor trip mechanism. Arrangement of components inside the buildings, checking for operability, initiation of corrective actions in the case of malfunctions, criteria for the initiation of the emergency boration system.
- Rates of motion and the drop times of the control rods.

9.7 Reactor Protection System

- Functions to be performed, layout, different modes of functioning and logic, monitoring for operability and functionality, identification of malfunctions.
- Activation criteria of various reactor protection system signals, interpretation of the state of the plant.
- In-service inspections according to technical specifications.

9.8 Containment

- Functions to be performed and different modes of functioning, including containment isolation, arrangement of components and systems in the containment, initiation of corrective actions in the case of malfunctions, containment design limits.
- Maintenance of negative pressure, heat removal from containment, H2 control.
- Arrangement of the containment isolation valves in the individual systems.
- Influence of isolation of penetration, and/or penetration of containment shell, on the reactor auxiliaries.

9.9 Instrumentation and Alarm System

- Functions to be performed by the instrumentation of the active and passive safety systems and the associated alarm annunciators. Incident instrumentation, measuring methods.
- Design limits of the measuring system.

9.10 Reactor Auxiliaries

- Functions to be performed and different modes of functioning, arrangement of the components in the buildings, integration of the measured data for the identification of the operating state, possible modes of operation, influence of the respective mode of operation on adjacent systems, and initiation of corrective actions in the case of malfunctions with respect to the following systems:
  - Chilled water system;
  - Ventilation systems;
  - Containment spray system;
  - Containment ventilation systems;
  - Reactor cavity and spent fuel pool cooling and purification system;
  - Chemical and volume control system;
  - Reactor boron and water make-up systems;
  - Nuclear sampling and plant radiation monitoring systems;
  - Safety injection system;
  - Nuclear vents and drains systems;
  - Residual heat removal system;
  - Component cooling system;
  - Essential service water system;
  - Air supply systems; and
  - Effluent treatment systems.
- Activation criteria and prerequisites for commissioning and manual interventions with respect to the following systems:
  - Containment spray system;
  - Safety injection system;
  - Residual heat removal system;
  - Component cooling system;
  - Essential service water system;
  - Air supply systems; and
  - Ventilation systems.

9.11 Conventional Service Systems

- Functions to be performed, different modes of functioning and arrangement of the components in the buildings. Functions to be performed by the instrumentation of the following systems:
  - Service water systems, fire extinguishing systems;
  - Air-conditioning systems and ventilation systems; and
  - Fire and gas protection equipment.

9.12 Water-steam Circuit

- Functions to be performed, different modes of functioning, arrangement of the components in the buildings, design limits and operating data, tasks of the controls, interpretation of the measured data for the identification of the operating state, possible modes of operation and influence of the respective mode of operation on the connected systems. Initiation of corrective actions in the case of malfunctions with respect to the following systems and units:
  - Turbine and condenser;
  - Turbine bypass system;
  - Condensate system;
  - Feed water systems;
  - Auxiliary feed water system; and
  - Safety valves and blowdown systems.

9.13 Cooling Water Systems

- Functions to be performed, different modes of functioning, arrangement of the components in the buildings, interpretation of the measured data for the identification of the operating state, possible modes of operation, influence of the respective mode of operation on adjacent systems and initiation of corrective actions in the case of malfunctions with respect to the following systems:
  - Closed cooling systems;
  - Residual heat removal systems; and
  - Reactor coolant systems.

9.14 Electrical Systems

- Functions to be performed, different modes of functioning, arrangement of the components in the buildings and activation criteria for placing into operation the various systems for the generation of emergency power to the essential bus bars. Survey of the emergency power loads important to safety and initiation of corrective actions in the case of malfunctions.
- Functions to be performed, different modes of functioning, arrangement of the components in the buildings, possible modes of operation for the auxiliary power system, survey of the auxiliary power supply and its most important loads as well as the mains connection and manual actions for establishing the auxiliary power supply.

10. CONTROL ROOM

10.1 Control Room and Auxiliary Control Panels

- Physical arrangement of the control room including the allocation of systems and equipment.
- Operation and scope of application of the information, communication and documentation equipment accommodated in the control rooms and ancillary rooms.
- Explanation of the identification system of the plant.
- Functions to be performed and meaning of the actuation and display fields of the panels.
- Diagnosis of the state of the plant including normal instrument displays, incident instrumentation and reactor protection panel.
- Functions to be performed and location of the auxiliary control panels, including emergency shutdown panels.

10.2 Control Room Engineering

- Meaning of codings; display, signal and actuation equipment; allocation to the respective systems or components; meaning, handling and operating conditions of the key operated switches.
- Malfunction in control room engineering and corrective actions.
- Mode of functioning and operation of the alarm systems.

10.3 Computer Systems

- Functions to be performed, different modes of functioning, arrangement of the components in the buildings, design limits and operating data, tasks of the controls, interpretation of the measured data, possible modes of operation, influence of the respective mode of operation on the systems connected and initiation of corrective actions in the case of malfunctions with respect to the computer system or with the data received from the system.

11. PLANT OPERATION

- Explanation of the startup and shutdown of the reactor from various states of operation, as well as its power operation, in compliance with procedures and Operating Technical Specifications.
- Operating transients and behaviour of the plant.
- Characteristic development of the essential operating data during startup and shutdown.
- Effects of secondary side operating parameters on the primary side operating parameters.
- Admissible maximum temperatures and differences during startup and shutdown regarding thermal shock and brittle fracture.
- Thermal hydraulic processes during heat transfer in the reactor pressure vessel.
- Explanation of the operating processes of individual systems on the basis of Operating Technical Specifications, including in-service inspections and periodic testing.
- Interpretation of the measured data and changes in measured data which are necessary for the identification of the state of the plant, including identification of malfunctions of individual systems.
- Interpretation of signals which are indicative of malfunctions and incidents.
- Explanation of the necessary automatic actions and of the possible manual interventions in the case of individual systems.
- Explanation of the in-service inspections of safety systems (scope and date of inspection) in compliance with Operating Technical Specifications and procedures.
- Operation and monitoring of airlocks.
- Operation of fire extinguishing equipment and respirators as well as other firefighting measures.
- Operation of the fire protection panel in the control room.
- Functions to be performed by shift personnel when fuel handling is in progress.
- Tests of the emergency systems from the emergency shutdown panel.
- Prescribed measures with respect to the discharge of liquid and gaseous effluent.

12. ABNORMAL OPERATING EVENTS

12.1 Malfunctions of Important Systems

- Identification, consequences and measures to be taken in the case of malfunction of the following systems:
  - Reactor coolant circuit, reactor coolant pumps, pressuriser.
  - Reactor control systems, scram operation.
  - Instrumentation.
  - Containment.
  - The following systems (with a view to radiological protection): sampling systems in the nuclear island, vents and drains on the nuclear island, plant release pathways.
  - Reactor auxiliaries.
  - Systems of the water-steam circuit, as well as the feed water pumps, the condensate pumps, the circulating water pumps.
  - The conventional service systems.
  - The cooling water systems.
  - Electrical power supplies and boards.

12.2 Abnormal Operation and Incidents

- Identification of the respective states of the plant, in particular of subcriticality and removal of residual heat from the reactor core on the basis of the status tree monitoring and others; checking the safety systems for conforming function on the basis of the incident; required measures for assuring long-term subcriticality and the removal of residual heat from the reactor core. Interaction of the various safety systems during various states of the plant and the possibilities of manual intervention in accordance with operating procedures and background documentation.
- Identification and development of the malfunctions and incidents including, but not limited to, those listed below; explanation of the malfunction effects on reactor operation, the plant and the environment; methods used for the determination of the cause of incidents; interpretation of annunciators and other systems for the clarification of the causes; measures for the elimination of the incident; cause and possibilities for the minimisation of the activity discharge; application of the incident related operating rules.
- Loss of instrument air to various headers, affecting plant performance.
- Loss or degraded electrical power to the station including:
  - Loss of offsite power, with successful house load.
  - Loss of emergency power, failure of emergency diesel generators.
  - Loss of power to electrical distribution boards.
  - Loss of power to the individual instrumentation boards (AC as well as DC) that provide power to control room indications or plant control functions affecting plant response.
- Malfunctions affecting the reactor coolant pumps, including vibrations and seal failures.
- Loss of forced reactor coolant flow due to single or multiple pump failure.
- Loss of condenser vacuum.
- Loss of service water or cooling to individual components.
- Loss of component cooling system or cooling to individual components; leaks on the component heat exchangers inside and outside of containment.
- Loss of normal feed water; failures of pumps, valves affecting the feed water system.
- Failure of a train of the protection system.
- Control rod failures.
- Inability to drive the control rods.
- Fuel cladding failure.
- Turbine and generator malfunctions.
- Turbine trip; generator trip.
- Failure of the following automatic control systems:
  - Rod control systems;
  - Chemical and volume control system;
  - Steam dump system; and
  - Feed water control system.
- Failure of the pressuriser pressure and level control system.
- Reactor trip.
- Failure of any nuclear instrumentation channel.
- Failure of any process instrumentation channel, alarm, control system, related to:
  - Rod control systems;
  - Chemical and volume control system;
  - Steam dump system;
  - Feed water pump and feed water control system;
  - Pressuriser pressure and level control system; and
  - Turbine control system.
  - Any channel that has an input into the protection system.
- Leaks on chemical volume control system.
- Leaks on condensate, feed water and steam system.

- Passive failures in systems such as the engineered safety features and the emergency feed water system.
- Malfunction of any major component of the important systems.
- Loss of coolant due to:
  - Significant SG tube leaks; single and multiple SG tube ruptures;
  - Inside and outside containment (loss of recirculation);
  - Small break LOCA;
  - Large LOCA; and
  - Failure of safety and relief valves.
- Total loss of all AC power (offsite and onsite).
- Complete loss of feed water (normal and emergency).
- Main streamline break as well as main feed line breaks, inside and outside containment.
- Failure of the automatic reactor trip system (ATWS).
- Accidents causing a serious threat to the plant's critical safety functions, such as:
  - Inadvertent return to criticality after a reactor trip.
  - Failure of emergency core cooling systems during a LOCA which results in core exit thermocouple temperatures in excess of 650 °C.
  - Accidents inside containment that result in containment pressures in excess of the design values and hence to containment failure.
  - SG tube rupture, combined with a secondary side leak (stuck open safety valve), or combined with a loss of AC power.
  - Loss of coolant accidents combined with instrumentation failure or drift.
- Natural circulation cools down with the formation of a steam bubble in the reactor vessel head.
- Loss of natural circulation in one or more loops.

12.3 Unforeseen Event Sequences

- Design limits:
  - Design limits of the components and systems important to plant safety such as the reactor pressure vessel, containment, steam generators, emergency core cooling and the residual heat removal system.
- Aims of protection which determine the safety of the plant such as:
  - Subcriticality;
  - long-term core cooling;
  - Heat removal from the reactor coolant;
  - Power supply; and
  - Activity confinement.
- Safety parameters:
  - The plant-specific measured data which determine the aims of protection and their admissible ranges.
- Safety functions:
  - The functions that assure compliance with the aims of protection and their effectiveness, such as reactor scram, safety injection and containment isolation.
- Core damage:
  - Possibilities of the identification of precursors to core damage, such as high core outlet temperature and high primary circuit activity.
- Identification of critical states:
  - Measured data that, when exceeded, endanger the aims of the protection and are indicative of failures or ineffectiveness of safety functions, such as neutron flux measurement, reactor coolant level, reactor coolant temperature, fuel element temperatures, main steam pressures, air activity, and busbar voltages.

13. ADDITIONAL MONITORING REQUIREMENTS

13.1 Environmental Monitoring

- Measuring instruments for environmental monitoring (e.g. liquid wastes, stack, metrological data, steam releases) with display or alarm in the control room.
- Countermeasures in the case of increasing activity discharges in a release pathway.
- Monitoring of activity discharges through the stack.

13.2 Chemistry Monitoring
- Monitoring of the chemistry of the various circuits.

13.3 Access Control
- Control of access to the individual buildings or compartments.

13.4 Radiological Protection Monitoring
- Must be familiar with the type of instrumentation and mode of functioning for the following purposes:
  - Personnel monitoring; and
  - Area monitoring.

14. ADMINISTRATIVE REQUIREMENTS

14.1 Control Room and Shift Duties
- Scope of duties of persons on shift.
- Responsibilities and authorities within a shift.
- Responsibilities and authorities of top management, other management personnel and Radiation Protection staff with respect to shift personnel.

14.2 Control Room Response to Emergencies
- Alarm equipment in the nuclear power plant.
- Signals, behaviour and measures taken at various stages.
- Preconditions and responsibilities for the initiation of the emergency plan.
- Notifications.
- Duties and responsibilities of shift staff during a nuclear emergency.

14.3 Operating Documentation
- Structure, contents and handling of documentation including the safety specifications as well as any additional plans, drawings and descriptions that may be required.

14.4 Conditions Imposed and Documents Issued by the Regulator
- Reporting requirements with respect to non-conformance with the Regulatory requirements.
- Survey of the conditions imposed and the documents issued by the Regulator with respect to operations.

14.5 Other Operating Rules
- Important details for shift operation as part of the duties and responsibilities of the shift staff.

15. IN PLANT (WALK-THROUGH)

A reactor operator should have the following areas of knowledge to perform satisfactorily during normal, abnormal and incident operations when occupying a registered position. When asked to locate equipment which is operated from the control room or is displayed on the control room mimic panels, the operator will either go directly to the exact location, or be able to explain to an NPO where the location is and how the equipment is operated.

15.1 Control Room

- Shift handover:
  - Verbal exchange, shift changeover sheet, emergency duty roster, control room log, review of limiting condition of operation, temporary operating instruction, specific instructions, temporary alterations and out of normal boards.
- Administrative procedures/controls:
  - Periodic tests, permits to work, specific instructions, interface with interconnected power system, mechanical drawings, instrumentation drawings, defects, admin lockouts and use of inhibit keys.
- Control room equipment:
  - Communication equipment, intercom, PA system, alarms, ringmaster, sound power phones, in-plant cameras, emergency telephones, plant information system, fire panel, common panel, neutron power detector cabinets, radiation detector sheets and control room leak rate sheets.
- Control room tasks.
  - Various control room tasks which will encompass all areas that an operator may have to perform during normal, abnormal or incident operations.

15.2 Electrical Building

- Various tasks which will encompass all areas that an operator may have to perform during normal, abnormal or incident operations.

15.3 Electrical Distribution

- All non-essential, essential and continuous.

15.4 Emergency Shutdown Panel

- Panel operations and communications.

15.5 Nuclear Auxiliary Building

- All systems and components of the Nuclear Auxiliary Building, including the diesels. An operator or candidate should be able to:
  - Locate a component;
  - Explain its function; and
  - Explain the impact on plant operation if the component fails.

15.6 Reactor Building

- All systems and components of the reactor building. An operator or candidate should be able to:
  - Locate a component;
  - Explain its function; and
  - Explain the impact on plant operation if the component fails.

15.7 Turbine Hall

- All systems and components of the Turbine Hall of which the Outside Plant are considered to be part. An operator or candidate should be able to:
  - Locate a component;
  - Explain its function; and
  - Explain the impact on plant operation if the component fails.

15.8 Additional Duties and Responsibilities

- The following should be able to be demonstrated when an operator is on shift:
  - Radiological controls;
  - Personal monitoring, personnel monitoring equipment and its use, radiation protection certificate;
  - Plant safety;
  - Fire protection, hazardous area entry, hazardous material, security;
  - Emergency plan duties; and
  - Duties of shift staff in emergency conditions.

15.9 Nuclear Security and Nuclear Safety Culture

- Applicable international best practice in accordance to establishing and maintaining a healthy nuclear security culture.
- Applicable international best practice in accordance with establishing and maintaining a healthy nuclear safety culture.