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Accident Management: Severe Accident Management Programs for Nuclear Reactors

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Accident Management: Severe Accident Management Programs for Nuclear Reactors
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Preface

This regulatory document is part of the CNSC's Operating Performance series of regulatory documents. The full list of regulatory document series is included at the end of this document and can be found on the CNSC's Web site at nuclearsafety.gc.ca/regulatory-documents

This regulatory document sets out the expectations and guidance of the Canadian Nuclear Safety Commission (CNSC) with respect to severe accident management programs.

Issued as REGDOC-2.3.2, this document is the second version of *Severe Accident Management Programs for Nuclear Reactors*. It supersedes the previous version of the same title that was identified as G-306. REGDOC-2.3.2 includes amendments to reflect lessons learned from the Fukushima nuclear event of March 2011, and to address findings from the *CNSC Fukushima Task Force Report*, as applicable to G-306.

This document is intended to form part of the licensing basis for a regulated facility or activity. It is intended for inclusion in licences, either as part of the conditions and safety and control measures in a licence, or as part of the safety and control measures to be described in a licence application and the documents needed to support that application.

Important note: Where referenced in a licence either directly or indirectly (such as through licensee-referenced documents), this document is part of the licensing basis for a regulated facility or activity.

The licensing basis sets the boundary conditions for acceptable performance at a regulated facility or activity and establishes the basis for the CNSC's compliance program for that regulated facility or activity.

Where this document is part of the licensing basis, the word "shall" is used to express a requirement, to be satisfied by the licensee or licence applicant. "Should" is used to express guidance or that which is advised. "May" is used to express an option or that which is advised or permissible within the limits of this regulatory document. "Can" is used to express possibility or capability.

Nothing contained in this document is to be construed as relieving any licensee from any other pertinent requirements. It is the licensee's responsibility to identify and comply with all applicable regulations and licence conditions.

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1. Introduction

1.1 Purpose

The purpose of this regulatory document is to help a person who applies for, or holds, a licence to construct or operate a nuclear reactor to develop and implement a severe accident management (SAM) program, in accordance with the *Nuclear Safety and Control Act* (NSCA).

1.2 Scope

This document describes a typical SAM program for a nuclear reactor. A person who applies for, or holds, a licence to construct or operate a nuclear reactor should follow this guide when developing and implementing measures to help:

- prevent the escalation of a reactor accident into an event involving severe damage to the reactor core
- mitigate the consequences of an accident involving severe damage to the reactor core
- achieve a safe, stable state of the reactor and plant over the long term

1.3 Relevant legislation

While the NSCA and its regulations do not expressly refer to SAM programs for nuclear reactors, several of their provisions are relevant to this guide:

- Paragraph 3(a) of the NSCA provides for the limitation "to a reasonable level and in a manner that is consistent with Canada's international obligations of the risks to national security, the health and safety of persons, and the environment, that are associated with the development, production, and use of nuclear energy."
- Subsection 24(4) of the NSCA stipulates that "no licence may be issued, renewed, amended, or replaced unless, in the opinion of the Commission, the applicant (a) is qualified to carry on the activity that the licence authorizes the licensee to carry on, and (b), in carrying on that activity, will make adequate provision for the protection of the environment, the health and safety of persons, and the maintenance of national security and measures required to implement international obligations to which Canada has agreed."
- Paragraph 12(1)(*f*) of the *General Nuclear Safety and Control Regulations* requires every licensee to take all reasonable precautions to control the release of radioactive nuclear substances within the site of the licensed activity and into the environment as a result of licensed activity.
- Paragraph 6(*k*) of the *Class I Nuclear Facilities Regulations* stipulates that an application for a licence to operate a Class I nuclear facility shall contain information on the proposed measures to prevent or mitigate the effects of accidental releases of nuclear substances on the environment, and the health and safety of persons.

2. Overview

A SAM program provides an additional defence against the consequences of those accidents that fall beyond the scope of events considered in the reactor design basis. The establishment of a

SAM program should ensure that personnel involved in managing an accident have the information, procedures, and resources necessary to carry out effective on-site actions.

To the extent practicable, a SAM program builds on existing emergency operating procedures and emergency preparedness measures. The specific provisions of a SAM program take the reactor design into account, particularly the reactor power and available protective systems. For reactors of low thermal power, it may be possible to show that certain elements of a SAM program are unnecessary or not applicable. The licensee is responsible for demonstrating that a SAM's provisions are adequate in limiting the risk posed by severe accidents.

SAM is intended to bring the reactor – and the plant in general – into a controlled and stable state. Long-term onsite recovery actions, as well as offsite actions, are beyond the scope of a SAM program.

3. Goals and Principles of Severe Accident Management

The licensee should adhere to the goals and principles outlined in subsections 5.1 and 5.2 when developing a SAM program.

3.1 Severe accident management goals

The goals of an effective SAM program include:
- terminating core degradation early
- achieving a stable and controlled state of the reactor core or core debris
- maintaining containment integrity
- minimizing the release of radioactive products into the environment

3.2 SAM principles

The principles of an effective SAM program include:
- ensuring a balance between reliance on organizational measures and design capabilities
- identifying the roles and responsibilities of the operating staff and special emergency teams
- identifying and evaluating plant systems and features suitable for use during severe accident management, including those not originally designed for accident management
- providing adequate training to the operating staff and special emergency teams

4. Considerations for Program Development

Results of risk assessment and accident analysis are important considerations for SAM program development.

4.1 Risk assessment

The results of probabilistic risk assessment should assist the licensee to:
- verify that SAM would be effective for representative severe accident sequences, including multi-unit events, events triggered by natural and human-induced external hazards, and for accidents where station blackout lasts for at least 72 hours (station blackout is also known as "extended loss of alternating current [AC] power")
- provide a basis for the assessment of safety benefits of potential design enhancement options

- identify accident scenarios for personnel training and drill purposes

4.2 Accident analysis

The results of an accident analysis should assist the licensee to:

- specify the criteria that would indicate the onset of a severe accident
- identify the symptoms (i.e., parameters and their values) by which plant personnel may determine the reactor core condition and state of protective barriers
- identify the challenges to fission product boundaries in different reactor states, including shutdown states
- evaluate the timing of such challenges, in order to improve the potential for successful human intervention
- identify the plant systems and material resources that may be used for SAM purposes
- verify that SAM actions would be effective to counter challenges to protective barriers
- evaluate performance of instrumentation under accident conditions
- develop and validate computational aids for SAM

5. Defining High-Level Accident Response

The licensee should define categories of accident response actions and carry out evaluations of systems and equipment, along with the assessment of material resources needed to perform those actions.

5.1 Preventive and mitigating actions

The licensee should identify practical preventive and mitigation actions to achieve the SAM goals. Generally, accident management actions should include:

- establishing and maintaining reactivity control
- ensuring availability of a heat sink for the heat generated in the reactor core
- depressurizing the primary heat transport system
- maintaining coolant inventory in the primary heat transport system
- controlling pressure and water inventory in steam generators
- ensuring containment isolation
- controlling the containment pressure and temperature
- controlling the concentration of flammable gases
- controlling radioactive releases

5.2 Evaluation of systems and equipment

Plant design capabilities for severe accident management (such as containment venting, hydrogen mitigation and coolant make-up provisions) should be identified.

For all systems and equipment expected to perform in a manner or under conditions that were not considered in their original design, the licensee should conduct an assessment of their potential availability, effectiveness, and limitations for use in support of a SAM program. Existing systems may warrant design enhancement, if the assessment reveals that the potential consequences of severe accidents are such that the existing systems may not provide the desired preventive and mitigating capabilities.

Essential plant monitoring features and instrumentation for diagnosis of plant state should be identified; reasonable assurance that these instruments and features will function reliably and provide meaningful data under severe accident conditions should be demonstrated.

5.3 Assessment of material resources

The licensee should perform an assessment to determine the availability of coolant, energy, and other material resources that may be required for the effective completion of SAM actions.

For procurement of external resources (equipment, power, water and staff), the licensee should assess the adequacy of arrangements with other organizations, in order to ensure these resources would be available and accessible in a timely manner during accidents. Consideration should be given to potential challenges posed by common-cause / external events. These arrangements should be formalized and documented.

6. Severe Accident Management Procedures and Guidelines

The licensee should develop SAM guidelines and procedures that account for factors specific to the plant design. They should also include:

- the organizational structure of the SAM program within the facility, with identification of the roles and responsibilities of every program participant, including operating staff and emergency response and support groups
- the parameters that define the transition from emergency operating procedures to SAM procedures
- key parameters to diagnose the state of various reactor and plant systems throughout the progression of the accident
- actions to be taken to counter challenges to the reactor and plant systems
- indicators that can be used to judge the success of the implemented actions
- the communication protocol to be followed during SAM implementation

In developing SAM procedures and guidelines, the licensee should consider that the information available to the operating staff or emergency groups may be incomplete and characterized by significant uncertainties.

7. Other Considerations

An effective SAM program should identify information and training requirements for the operating staff and emergency teams.

7.1 Information needs

In determining the information needs, the licensee should address the following aspects:

- the need to diagnose that a severe accident is occurring
- the need to determine the state of various plant systems – especially the reactor core, the primary heat transport system, emergency cooling systems, major heat sinks, and containment system
- the need to obtain information on key parameters, such as neutron flux, temperatures, pressures, flows, combustible gas concentrations, and radiation levels
- the need to confirm the effectiveness of SAM actions

The licensee should also assess the availability and accuracy of instrumentation and information management systems credited in SAM.

During an accident, the total information flow may be overwhelming and some indications may be contradictory because of failed equipment. Given this consideration, the licensee should consider using diagnostic and support tools to help emergency teams with decision-making.

7.2 Personnel training

In determining the information needs, the licensee should address the following aspects:

- understand roles and responsibilities within the SAM program
- learn about severe accident phenomena and processes
- become familiar with the activities to be carried out
- enhance the ability to perform in stressful conditions
- verify the effectiveness and improve the clarity of SAM procedures and guidelines; this includes the need to obtain information on key parameters (such as neutron flux, temperatures, pressures, flows, combustible gas concentrations, and radiation levels)

Training programs should address the roles to be performed by the different groups involved in SAM. These programs should include drills and exercises that make it possible to evaluate how the various groups interact.

The licensee should develop a set of drills to cover multi-unit events (as applicable to multi-unit NPPs) and events triggered by external events.

To the extent practicable, the licensee should use simulator training because it provides a realistic, interactive environment and is efficient in enhancing human response in complex situations.

7.3 Organizational responsibilities and interfaces

Clearly defined roles and responsibilities of involved personnel and organizations are an essential component of an effective SAM program.

7.3.1 Identification of organizational groups

The licensee should establish the roles and responsibilities of the following participants:

- control room operators
- field personnel
- shift supervisors and shift managers
- station emergency response groups
- station management
- advisory and supporting groups
- corporate utility emergency centre personnel

The licensee should also establish qualification, training, deployment, and staffing numbers for the various organizational groups involved in the management of severe accidents.

7.3.2 Communication interfaces

During a severe accident, no single group will have the complete information, knowledge, and skills required to manage the accident. It is therefore important to establish effective communication interfaces among groups. These interfaces will allow efficient integration of the information and expertise available within the operating organization, or from other involved authorities.

An effective communication interface between the operating organization and the provincial and other appropriate emergency organizations should clearly delineate responsibilities. It should also specify the scope and timing of the information and the support that the provincial emergency organization and other involved organizations will receive.

8. Validation and Review

The licensee should validate a SAM program when it is established, in order to confirm its effectiveness, usability, technical accuracy and scope. This validation should include modelling of selected accident scenarios (with and without consideration of accident management actions), as well as drills and exercises.

The validation should demonstrate with a reasonable level of confidence that:

- the means (such as intervention of emergency response crews, or mitigating equipment) are available and can be deployed
- the operator actions are possible, accounting for variables such as ease of access, possible radiation fields, presence of debris, fires or flooding
- qualified staff are available in sufficient numbers

The licensee should also perform periodic reviews of a SAM program, provisions, guidelines, and procedures to reflect changes in plant design, operational modes, or organizational responsibilities. The reviews should address new information that has been derived from drills, exercises, training programs, safety analyses, experimental research or other sources.

9. Documentation

The licensee should provide the CNSC with the following information about a SAM program:

- goals and principles used for development and implementation of the SAM program and provisions
- results of probabilistic, analytical and design studies conducted in support of SAM
- results of assessments of the efficiency of preventive and mitigating actions
- SAM guidelines and procedures
- performance capabilities for the systems and equipment that can be used in support of SAM procedures
- information requirements for effective accident management
- responsibilities of persons and organizations involved in SAM
- requirements for personnel training
- results of SAM validation and reviews

Glossary

accident
Any unintended event, including operating errors, equipment failures or other mishaps, the consequences or potential consequences of which are not negligible from the point of view of protection or safety.

beyond-design-basis accident (BDBA)
Accidents less frequent than a design-basis accident. A beyond-design-basis accident may or may not involve core degradation.

design-basis accident (DBA)
Accident conditions against which a nuclear power plant is designed according to established design criteria, and for which the damage to the fuel and the release of radioactive material are kept within regulated limits.

licensing basis
A set of requirements and documents for a regulated facility or activity, comprising:

- the regulatory requirements set out in the applicable laws and regulations
- the conditions and safety and control measures described in the facility's or activity's licence and the documents directly referenced in that licence
- the safety and control measures described in the licence application and the documents needed to support that licence application

mitigation
Measures aimed at limiting the scale of core damage, preventing interaction of the molten material with containment structures, maintaining containment integrity, and minimizing offsite releases.

prevention
In the context of severe accident management, measures aimed at averting or delaying the onset of severe accident.

severe accident
An accident more severe than a design-basis accident, and involving significant core degradation or significant fuel degradation in the spent fuel pool (also called the irradiated fuel pool).

severe accident management (SAM) program
A program that establishes:

- the actions to be taken to prevent severe damage to the reactor core, to mitigate the consequences of the core damage (should it occur), and to achieve a safe, stable state of the reactor over the long term
- the preparatory measures necessary for implementation of such actions

station blackout
A complete loss of alternating current (AC) power from offsite and onsite main generator, standby and emergency power sources. Note that it does not include failure of uninterruptible AC power supplies and direct current (DC) power supplies. It also does not include failure of alternate AC power.

Note: The requirements for Alternate AC power are provided in REGDOC-2.5.2, *Design of Reactor Facilities: Nuclear Power Plants*.

CNSC Regulatory Document Series

Facilities and activities within the nuclear sector in Canada are regulated by the Canadian Nuclear Safety Commission (CNSC). In addition to the *Nuclear Safety and Control Act* and associated regulations, there may also be requirements to comply with other regulatory instruments such as regulatory documents or standards.

Effective April 2013, the CNSC's catalogue of existing and planned regulatory documents has been organized under three key categories and twenty-five series, as set out below. Regulatory documents produced by the CNSC fall under one of the following series:

1.0 Regulated facilities and activities

Series
- 1.1 Reactor facilities
- 1.2 Class IB facilities
- 1.3 Uranium mines and mills
- 1.4 Class II facilities
- 1.5 Certification of prescribed equipment
- 1.6 Nuclear substances and radiation devices

2.0 Safety and control areas

Series
- 2.1 Management system
- 2.2 Human performance management
- 2.3 Operating performance
- 2.4 Safety analysis
- 2.5 Physical design
- 2.6 Fitness for service
- 2.7 Radiation protection
- 2.8 Conventional health and safety
- 2.9 Environmental protection
- 2.10 Emergency management and fire protection
- 2.11 Waste management
- 2.12 Security
- 2.13 Safeguards and non-proliferation
- 2.14 Packaging and transport

3.0 Other regulatory areas

Series
- 3.1 Reporting requirements
- 3.2 Public and aboriginal engagement
- 3.3 Financial guarantees
- 3.4 Commission proceedings
- 3.5 Information dissemination

Note: The regulatory document series may be adjusted periodically by the CNSC. Each regulatory document series listed above may contain multiple regulatory documents. For the latest list of regulatory documents, visit the CNSC's Web site at nuclearsafety.gc.ca/regulatory-documents