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Response to Commission Request for Information	Réponse à une demande d'information de la Commission
McMaster Nuclear Reactor	**Réacteur nucléaire de McMaster**
Public Hearing in Writing	Audience publique par écrit
Submitted by: CNSC Staff	Soumise par : Le personnel de la CCSN

Signed/signé le

17 April 2024

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C=CA, O=GC, OU=CNSC-CCSN, CN="Sigouin, Luc"

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Director General

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Background

In this CMD, CNSC staff provide responses in writing to questions from the Commission documented in CMDQ 24-H100-Q with respect to the public hearing in writing concerning the request from McMaster University to renew its operating licence for the McMaster Nuclear Reactor (MNR).

Questions from the Commission directed to CNSC staff, as well as staff responses, can be found in the next section.

Referenced documents in this CMD are available to the public upon request, subject to confidentiality considerations.

Staff Response

The Commission’s questions, including any quoted text from the original CMD, have been reproduced below in the shaded boxes to provide suitable context for CNSC staff’s responses.

#1	In light of the comments raised by D. Winfield on page 4 of CMD 24-H100.9, clarify: • the objective of the mid-term performance update • whether CNSC staff have guidance or expectations for licensees to prepare mid-term updates

In 2023, mid-term updates were provided for Chalk River, Bruce Nuclear Generating Station and Pickering Nuclear Generating Station. For longer licence terms recently granted by the Commission, mid-term updates have been included (e.g., Royal Military College SLOWPOKE-2 research reactor, Cameco Fuel Manufacturing) in the records of decision. At a high level, the objective is for the licensee to provide performance-related information and other information of interest to the Commission, the public and Indigenous Nations and communities.

Dr. Winfield notes in CNSC staff’s CMD the absence of any opportunity for public participation as part of the mid-term update. This was an omission in CNSC staff’s CMD. It would be expected for the MNR mid-term update, that the public and Indigenous Nations and communities be given the opportunity to participate. This has been the practice for mid-term updates to date.

Dr. Winfield also highlights the information provided in the Annual Compliance Reports (ACR) and how it may or may not relate to a mid-term update. ACRs are licensee documents that are publicly available, however, the dissemination thereof, is fairly limited. Information from ACRs could be used as part of a mid-term update.

With respect to CNSC staff guidance and expectations, current practice is that guidance from CNSC staff has typically been provided to the licensee specific to the facility in question leading up to the mid-term. In addition, direction regarding mid-term expectations has been provided in some Records of Decisions (e.g., Point Lepreau).

Dr. Winfield’s intervention draws parallels between the CNSC’s Safety and Control Area (SCA) framework and that of international frameworks, specifically the International Atomic Energy Agency’s (IAEA) periodic safety review (PSR) process. The SCA framework provides a useful framework for conveying performance-related information, whether it be part of an ACR, licence application or Regulatory Oversight Report. Should the MNR operating licence be renewed by the Commission, including the requirement for a mid-term by the licensee, CNSC staff anticipate this performance update to include relevant SCAs.

As Dr. Winfield points out, as a process, a PSR takes 2 to 3 years to complete. Under the *Class I Nuclear Facility Regulations*, only nuclear power plants have a requirement to undertake a PSR. There are no regulatory requirements or expectations at this time for research reactors to do likewise.

CNSC staff anticipate the approach to licensee mid-terms, such as content, format, etc. to continue to evolve over time. Feedback on mid-terms from the Commission, the Registry, Indigenous Nations and communities and the public will continue moving forward. As the timing of the mid-term approaches, CNSC staff will engage with MNR regarding the latest guidance on these matters.

#2	The MNR reactor pool is 65 years old. McMaster University has indicated its intention to operate on a schedule of 24-hours, 5-days/week in the future. As a result, should the assessment of the concrete condition, of the in-situ beam tubes and of the concrete embedded stainless steel coolant lines sections be expanded? Does CNSC REGDOC-2.6.3, Aging management, address these issues?

MNR has been operating on a 24-hour, 5-days/week schedule since March 18, 2024. Over the planning phase of this project, CNSC staff have discussed with MNR staff the potential impact of the increased operating schedule on existing structures, systems and components (SSC), and the adequacy of MNR's maintenance and aging management programs. Though part of MNR's current licensing basis, CNSC's review of this increased operating schedule is captured in CNSC staff's CMD 24-100.A. The new operating cycle is not expected to have any measurable impact on the concrete condition, the in-situ beam tubes or embedded stainless steel coolant lines, since the relatively long distance between the core and these SSCs, and the shielding from the water in the pool minimize radiation exposure and mitigate any significant radiation damage to these structures.

During the current licence period, CNSC staff have assessed MNR's fitness for service, the maintenance and the aging management programs through inspections and document reviews. Over the licence period, 5 inspections and other assessments led CNSC staff to conclude that MNR's performance on fitness-for service, including aging management and maintenance programs was satisfactory.

McMaster University's Technical Note TN 2010-04, *Status of McMaster Nuclear Reactor Structures, Systems and Components* [1] describes the SSCs at MNR, their condition and the high-level aging management requirements. The concrete structure of the pool, the beam tubes and all embedded piping have been, and continue to be the object of periodic inspections by McMaster University. All embedded piping and primary cooling system components are made of 316 and 304 stainless steel (SS). As such, degradation mechanisms associated with embedded aluminum piping seen at other reactors around the world are not expected. There is no concrete-embedded aluminum piping at MNR. The condition of the coolant lines is verified through direct inspection of the accessible regions of the piping after it enters the pump room, as part of the ongoing aging management plan. For stainless steel embedded in concrete, most common corrosion mechanisms involve chloride ions, galvanic corrosion or crevice corrosion, which can be exacerbated by fatigue in cyclical high-stress conditions. These mechanisms have not been observed and are not likely to be active at MNR. The reactor is also inside a containment building under controlled environmental conditions and thus, the SSCs are not subjected to degradation associated with outside environmental conditions.

The pool water chemistry is carefully controlled using filters and mixed-bed ion exchange columns designed to provide high purity water, which significantly reduces the possibility of chloride ion corrosion. This is evidenced by resistivity of the primary coolant, which is measured at least once per day in accordance with the MNR operating limits and conditions.

The pool continues to be the focus of attention under MNR’s maintenance and aging management programs. The reinforced concrete around the core is 2 meters thick and is thicker than most other research reactor concrete pools. This structure is subject to on-going inspections by MNR. Since construction, fine, capillary-sized leaks have been observed, monitored and repaired as required. Leakage is monitored through visual inspections and building sump level changes. Sump levels are recorded once per shift and tracked for significant changes. To-date, there have been no observable changes to the sump level rates that would suggest increases in capillary leaks through the concrete. Over the current licence period, CNSC staff have examined the condition of the pool, reviewed the leakage records and assessed the pool inspection activities by MNR staff. In general, the condition of the pool, including the leak rate, has improved over the licence period, following repairs and periodic maintenance activities by MNR.

MNR’s safety analysis report (SAR), which has been reviewed and accepted by CNSC staff, discusses the different failure modes that could compromise the integrity of the reactor. The analysis shows that there is no plausible initiator (i.e., that with a frequency of greater than 10^{-6} per year) that could cause a sufficiently rapid loss of pool inventory such that the core could be threatened. Even if a corrosion or other degradation mechanisms were at play, these events cannot produce a leak that could not be mitigated through normal engineering means, and there would not be a risk to the public, workers or the environment. Further, CNSC conclude that the flooding of a liner tube as discussed in the SAR would have no significant safety impact. Over the years, MNR staff have had occasional access to the inside of embedded beam tubes and there have been no detectable signs of corrosion.

REGDOC-2.6.3, *Aging Management*, sets out the requirements for managing the aging of SSCs. Although the document is written in the scope of power reactors, it is included in the proposed licence conditions handbook (LCH) as part of the MNR licensing basis, as most of the principles apply for a facility like MNR. These principles include topics that have been listed as compliance verification criteria in the current LCH and that were extracted from the IAEA SSG-10, *Ageing management for research reactors*.

Key requirements of REGDOC-2.6.3 applicable to MNR include:

- Licensees shall establish and implement processes, programs and procedures to manage aging and obsolescence of SSCs, to ensure that required safety functions are maintained during the facility operation phase;
- Facility operations shall be monitored and recorded to demonstrate compliance with critical service conditions, operational limits and conditions, and any other parameters that were identified as affecting aging assumptions used in safety analyses or equipment qualification;

- As part of the deterministic safety analysis review and update, licensees shall account for the effects of the aging of SSCs, research findings, and advances in knowledge and understanding of aging mechanisms. This shall include an evaluation of the cumulative effects of the aging of SSCs on overall system and facility safety performance, as well as on risk insights using probabilistic safety assessments.

Past CNSC compliance activities have verified that these requirements are complied with through MNR’s operating and aging management programs. The CNSC also participates in IAEA activities and programs, including the Incident Reporting System for Research Reactors (IRSRR), where any valuable international operating experience can inform CNSC compliance, including issuing requests for information to the licensees under section 12(2) of the *General Nuclear Safety and Control Regulations* to provide safety related information within a certain timeframe.

CNSC staff concluded that MNR’s expanded operating schedule does not have any measurable effects on the SSCs related to safety that are not already addressed by McMaster University’s existing maintenance and aging management programs. REGDOC-2.6.3 is included as part of the compliance verification criteria in the proposed LCH and compliance with this document will contribute to ensuring aging issues are effectively managed. CNSC staff will continue to inspect McMaster University’s maintenance and aging management programs, ensuring that pool condition, leak rates, and any signs of degradation are monitored during the next licence period.

Conclusion

CNSC staff confirm that the conclusions and recommendations made in CNSC staff's submission CMD 24-H100.A remain valid.

References

1. MNR Technical Note TN 2010-04 Rev. 1, Status of McMaster Nuclear Reactor Structures, Systems and Components, 10 April 2023, e-Doc 7035976

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MNR Technical Note TN 2010-04

Status of McMaster Nuclear Reactor Structures, Systems and Components

Revision 1

10 April 2023

MNR Technical Note TN 2010-04

Status of McMaster Nuclear Reactor Structures, Systems and Components

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ACRONYMS AND ABBREVIATIONS

ALARA	as low as reasonably achievable
ARMS	Area Radiation Monitoring System
IAMS	Iodine in Air Monitoring System
I&C	Instrumentation and Controls
CNSC	Canadian Nuclear Safety Commission
FPM	Fission Products Monitor
HUT	Hold-Up Tank
MNR	McMaster Nuclear Reactor
NPP	Nuclear Power Plant
P1	(Reactor) Pool 1, also known as Stall Pool section
P2	(Reactor) Pool 2, also known as Open Pool section
RCS	Reactor Coolant System
RHU	Reactor Hall Unit
RTD	Resistance Temperature Device
SSCs	Structures, Systems and Components
SSS	Safe Shutdown State
ST	Storage Tank

1. INTRODUCTION

This report compiles information on the present conditions of structures, systems and components (SSCs) in McMaster Nuclear Reactor (MNR) with consideration of aging effects as requested by the Canadian Nuclear Safety Commission (CNSC) [1].

Section 2 categorizes the MNR SSCs, identifies which of them are safety-critical and explains why these SSCs are safety-critical. The CNSC request [1] is for information on safety-critical SSCs. The information in this section is particularly important for readers who are not closely familiar with the MNR and its unique design and operation features.

Section 3 explains the methodology used for compilation of requested information and the terminology used in Sections 4 and 5

Section 4 compiles the information requested by the CNSC.

Section 5 provides information on SSCs other than safety-critical SSCs in the MNR. This information is background material which provides insights on the overall conditions of the facility.

Section 6 summarizes the information and outlines the path forward for maintaining safe and reliable operation of MNR.

2. SYSTEMS, STRUCTURES AND COMPONENTS OF MNR

In this report, the SSCs of the MNR are classified into three categories:

- Essential to nuclear safety.

  These SSCs are essential for achieving and maintaining the Safe Shutdown State of the reactor.

- Essential to personnel safety.

  These SSCs are essential for protection of MNR personnel.

- Other SSCs

  These SSCs are important to availability and reliability of MNR operation. They may also play a role as defence-in-depth provisions of MNR in preventing accidents and minimizing occupational exposures.

The first two categories are treated as safety-critical SSCs in the context of CNSC request for information. They are defined and described below, with further information provided in Section 4. The remaining SSCs are covered in Section 5 on best-effort basis[1].

2.1 SSCs Essential to Nuclear Safety

These SSCs are required to perform the three basic safety functions of any nuclear reactor:

(1) Achieve decay power level in the reactor core (i.e., shutdown).

(2) Dissipate decay heat from the fuel (i.e., cool).

(3) Maintain barriers to fission product release (i.e., confine radioactivity):

    a. Maintain fuel integrity.
    b. Maintain pool and Reactor Coolant System (RCS) boundaries.
    c. Maintain containment boundaries.

When these functions are executed, the reactor is in a Safe Shutdown State (SSS), which ensures that the public and the environment are protected.

The MNR SSCs which accomplish the Safe Shutdown State of the facility are described in detail by MNR TR 2009-01 [2], which was submitted to the CNSC as Appendix F of MNR Fire Hazard Analysis report [3]. A brief description of these SSCs is provided below.

The SSCs of shutdown function are schematically illustrated in Figure 2-1. They automatically or manually insert the neutron absorbers into the reactor core. Subsequently, the shutdown function is maintained passively (i.e., no further actions or services are required to maintain the core at decay power).

The SSCs of basic safety function 2 (i.e., the cooling function) are illustrated in Figure 2-2. They include the reactor pool structure, the beam tubes and a small portion of RCS piping up to and including the pool isolation valves. Once these valves are manually closed, which is the designated action for any unattended reactor state, the fuel is cooled passively for well over one

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[1] The best effort treatment of other SSCs is explained in Section 2.3.

week by the large inventory of pool water as demonstrated by operating experience[2]. Natural convection of pool water through reactor core in a 'stagnant' pool is achieved passively (i.e., without any operator action) by a so-called 'flapper' device, which is a part of core structure. Figure 2-3 illustrates this device and explains its passive operation principles.

The basic safety function of confinement is achieved by multiple, overlapping barriers. The fuel cladding and fuel matrix provide two barriers to release of radioactivity, thereby achieving safety function 3a. A submersion of fuel in a pool of water is required to maintain these two barriers to release. This is why the pool and RCS boundaries are listed under safety function 3b[3]. The containment envelope provides the barrier under accident conditions (safety function 3c). Figure 2-4 illustrates the SSCs that form the containment envelope (highlighted in red). Once the two isolation dampers are closed, the containment envelope is maintained passively[4].

The unique feature of MNR Safe Shutdown State is that, once established, it is totally passive. No services (e.g., electrical power, external water source, etc.) and no operator actions (other than monitoring) are required to maintain the SSS of MNR for well over one week. In turn, this unique feature reduces the number of safety-critical SSCs relative to that in Nuclear Power Plants (NPPs) or other research reactors, which typically require some services to be available quickly (i.e., within tens of minutes to few hours) for the maintenance of their SSSs.

2.2 SSCs Essential to Personnel Safety

The MNR reactor building (i.e., the containment envelope) is normally occupied when the reactor is in a state other than the unattended Safe Shutdown State. The workers are exposed to normal occupational hazards, such as elevated radiation fields in certain areas of the building. They may also be exposed to unanticipated hazards, such as an accidental release of radioactivity into building atmosphere or a major fire within the building.

The normal occupational hazards are mild and known. Therefore, the SSCs which minimize the occupational radiation exposures, and the other normal industrial hazards, to as low as reasonably achievable (ALARA) levels are not considered herein to be the 'safety-critical' SSCs. They are the 'other' SSCs, which do not pose imminent threats to life and health of personnel or to nuclear safety but are nevertheless monitored and maintained in good shape as part of sound operating practices.

The abnormal hazards may be sudden as well as severe in terms of threats to life and health of personnel. The MNR design and its procedures rely on timely detection of such hazards. Personnel protection is provided by means of early and complete evacuation of the reactor building whenever its internal conditions become hazardous[5], which is dependent on the ability to quickly establish the totally passive Safe Shutdown State discussed in Section 2.1. In this context, the SSCs that warn of abnormal hazards are critical to personnel safety. There are only two categories of the abnormal hazards: a radioactivity release into building atmosphere and a

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[2] Alternate configurations of RCS boundaries, which involve piping beyond the isolation valves and also provide the SSS of cooling system, are available in MNR as described in [2]. The RCS components beyond the isolation valves that constitute the alternate SSS are treated as defense-in-depth provisions and are covered in Section 5.1.

[3] Pool water also provides a barrier to release of condensable and soluble fission products.

[4] Operating experience shows that the containment envelope dissipates the decay heat released as vapor into the containment atmosphere passively (i.e., without reliance on atmosphere cooling equipment).

[5] Detailed explanation and discussion of this worker protection concept is provided in [3].

fire with associated smoke and heat hazards. The SSCs that detect and warn against these hazards are considered to be the safety-critical SSCs for MNR.

2.3 Other SSCs

The MNR has a number of active systems (as opposed to passive provisions) which are employed during normal operation to regulate core power, to dissipate fission heat and to provide habitable environment within the reactor building. Being a research reactor, facilities are also installed to perform experiments and irradiations in a manner that results in ALARA occupational exposures to radiation. Although not critical to nuclear or personnel safety, these other systems and facilities are essential for operation and may have a role as defense-in-depth provisions for nuclear and personnel safety.

The categories of SSCs in Section 5 are selected by judgment. They include the key active systems noted above as well as systems in which some components have become obsolete or experienced aging related symptoms resulting in already completed or planned replacement.

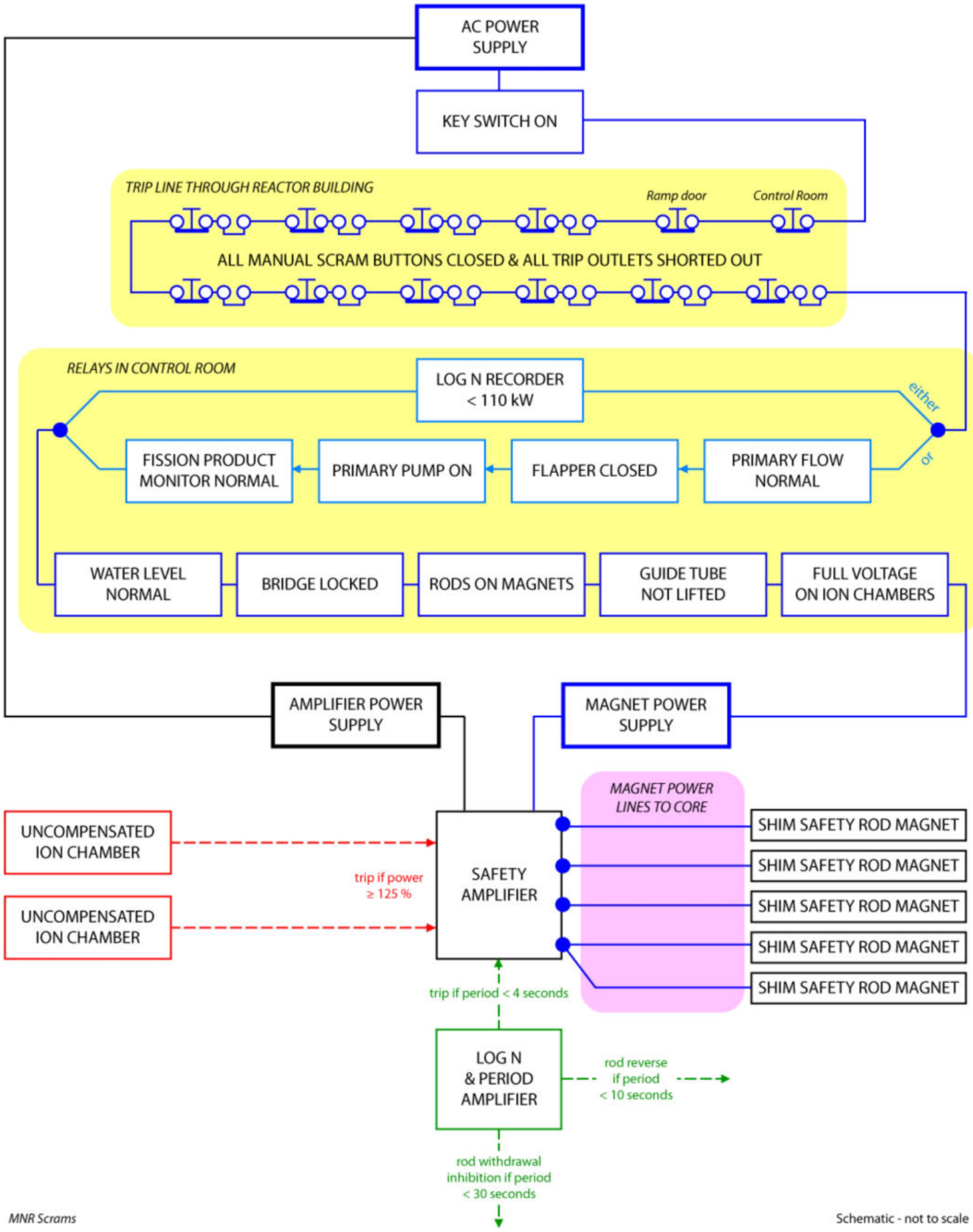


Figure 2-1 SSCs of Shutdown Function

(Figure 3-1 in MNR TR 2009-01 [2])

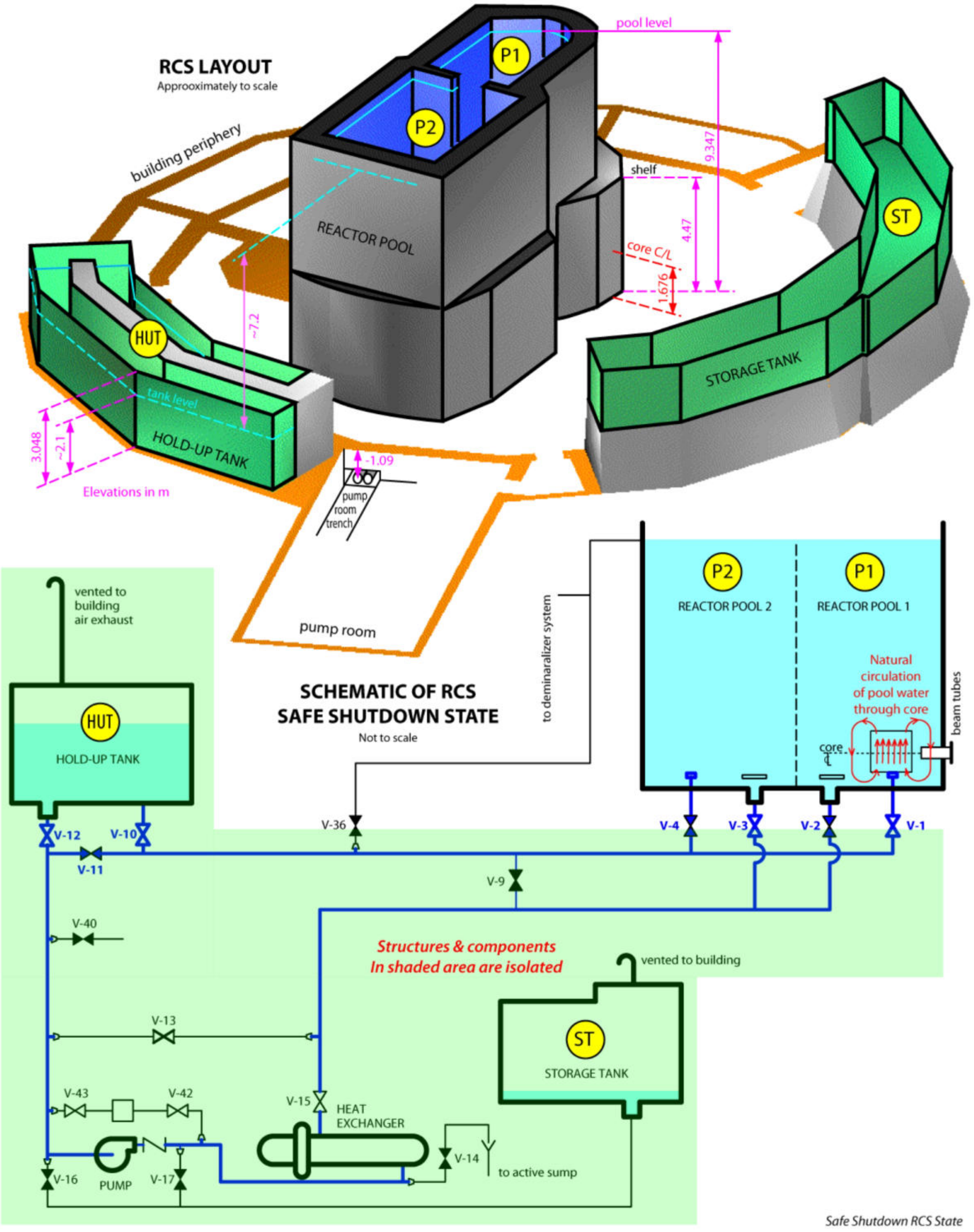


Figure 2-2 SSCs of Cooling Function

(Based on Figures 3-6 and 3-7 in MNR TR 2009-01 [2])

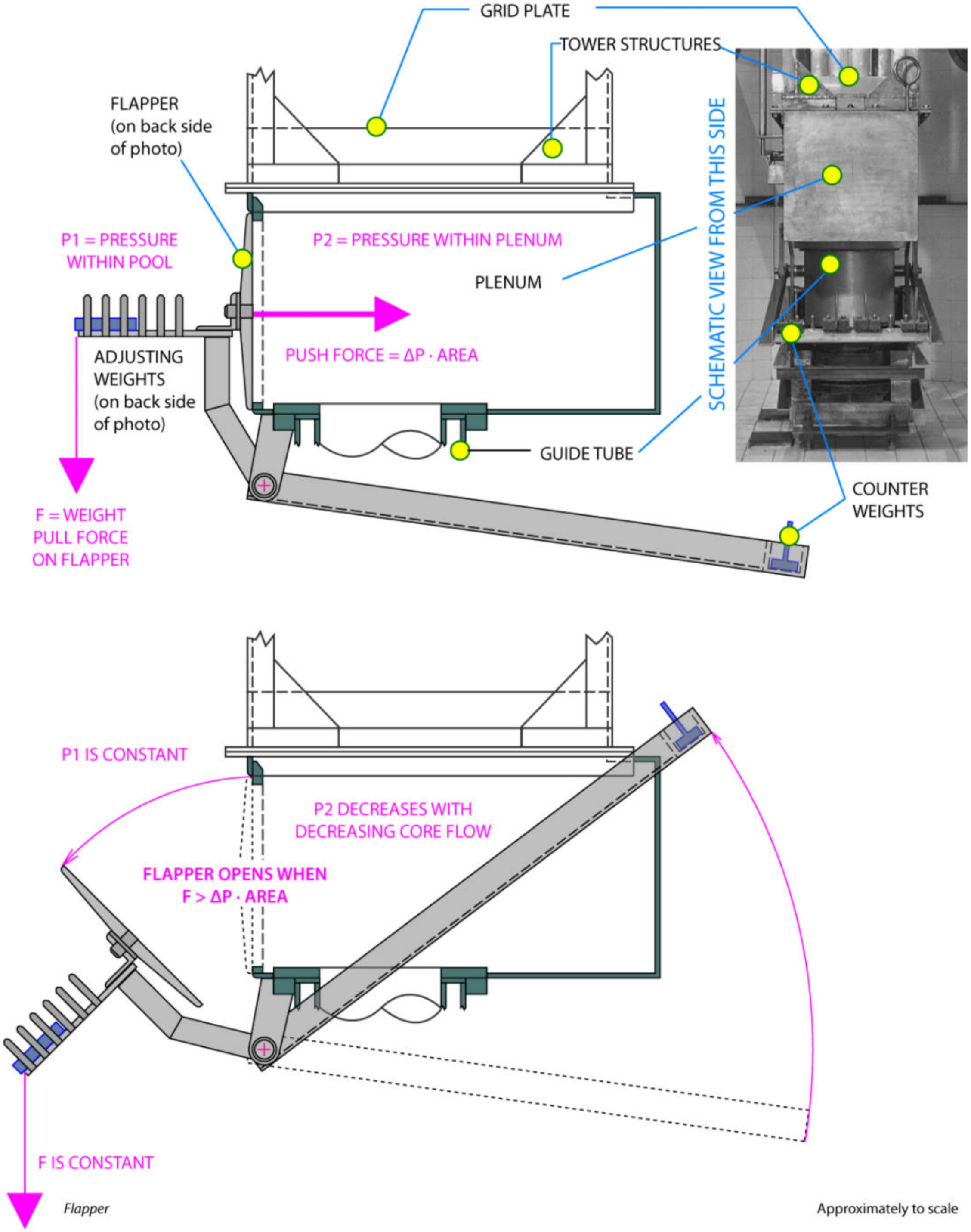
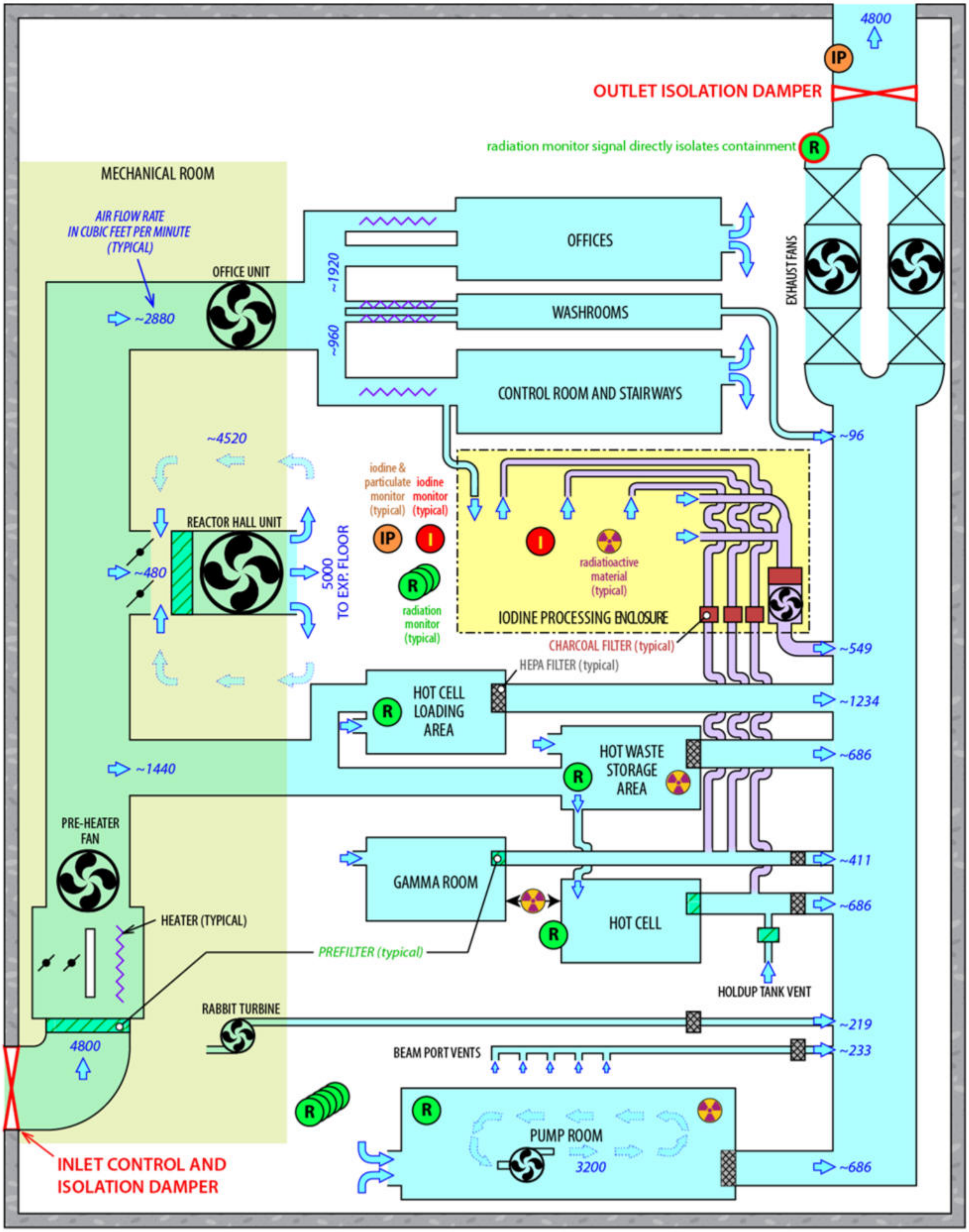


Figure 2-3 Flapper Device of Core Plenum

(Figure 3-8 in MNR TR 2009-01 [2])



09 MNR Ventilation Update 22-05-03

Schematic - not to scale

Figure 2-4 SSCs of Confinement Function 3c

(Figure 3-11 in MNR TR 200901 [2])

3. METHODOLOGY

3.1 Methodology for Compiling Information on SSC Conditions

The information in this report is compiled and organised according to hierarchy of SSCs in IAEA SSG-10, "Aging Management for Research Reactors" [4]. Although not ideal for capturing all unique features of MNR, Annex II of this standard provides a list of SSCs in research reactors considered by international authorities to be important to safety (organized in broader categories of structures and systems or subsystems) together with a list of potentially applicable aging mechanisms for each SSC. Information in Sections 4 and 5 follows the nomenclature and hierarchy of the IAEA list to avoid misunderstandings due to MNR specific terminology. Tables are compiled which list relevant aging mechanisms and add information requested by the CNSC staff related to 'monitoring of system health' (surveillances and tests performed) and refurbishment activities (maintenance activities and equipment replacements completed or planned). A conclusion on the condition of each safety-critical SSC is made by considered judgment of MNR staff taking into account both tangible (i.e., reported) factors and well as intangible (i.e., experience based) factors. For the other SSCs, the same topics are addressed but on a broader (system or subsystem) basis.

3.2 Glossary of Codes and Terms Used in Condition Tables

The aging mechanism codes in IAEA SSG-10 [4] are as follows.

1. Changes of properties due to neutron irradiation.
2. *Changes of properties due to temperature service condition.*
3. *Stress or creep (due to pressure and temperature service conditions).*
4. *Motion, fatigue or wear (resulting from cycling of temperature, flow and/or load, or flow induced vibrations)*
5. Corrosion
6. Chemical processes
7. Erosion
8. Changes of technology

The aging mechanisms in *italic font* are for environments that are not prototypic of MNR environments. Thus, these mechanisms "cannot be positively excluded but are outside the spectrum of reason". This expression is from [5] and it means extremely unlikely in plain language. Item 8 (changes of technology) is commonly called obsolescence. Item 4 is commonly called 'wear and tear', and it does not only stem from above listed environmental conditions but also from long term exposure to friction in rotating equipment (e.g., motor bearings) and long term mechanical interactions of subcomponents due to changes of operating states (e.g., relays). In this report, mechanisms 4 and 8 are reworded as follows:

4. Mechanical wear and tear due to interactions of moving components over long periods of time.
8. Obsolescence.

The code numbers are used in Table 4-1 and Table 5-1.

Surveillances, inspections, tests and maintenances have different details of processes, which are difficult to describe in a compact format. The conventions in Table 3-1 are adopted in this report. Table entries may or may not use the prefix code depending on the space available in the table field.

Table 3-1 Terminology of Performed Tasks

Prefix		**Task**	**Description**
Code	Term		
OD	On-demand	inspection, testing or maintenance	Done when deviation from normal condition occurs or is suspected to occur.
OO	On-opportunity	inspection	Done when circumstances allow it.
OP	Operational	testing	Done inherently when system or component is operated.
PF	Performance	testing	Done to monitor performance of a system.
PR	Preventive	maintenance	Done to avoid degradation of component or system performance before it occurs.
RT	Routine	surveillance	Done repeatedly according to established procedure or practice (reading sheet).
SCH	Scheduled	inspection, testing or maintenance	Done repeatedly according to prescribed schedule.

4. SAFETY CRITICAL SSCS AND THEIR CONDITION

The relevant SSCs broadly identified in Sections 2.1 and 2.2 are listed in Table 4-1. Explanations of table entries are provided below in the order of table headings. Rationale for the conclusion of current SSC conditions is provided towards the end of each subsection. Legend for terms and codes in the table is provided in Section 3.2.

4.1 Pool and Reactor Internals

4.1.1 Pool Structure

Safety Category: Nuclear

The nuclear safety function of this structure is to retain water (Section 2.1). The pool structure is illustrated at the top of Figure 2-2. It is a reinforced concrete structure with tiled internal surface. The water pool within the structure provides cooling and shielding for the reactor core. The pool is divided into two connected sections, which can be separated by a water-tight aluminium gate. The reactor may be located and operated in either section. Section P1 in Figure 2-2 houses the beam ports (discussed in Section 4.1.4). It is enclosed on three sides by two meter thick walls of heavy concrete to compensate for the reduced water shielding in this section. The remaining walls of the pool structure are approximately one meter thick and are made of regular concrete.

The pool structure is not leak tight. Small amounts of capillary leakage have persisted since the initial construction. The leakage is on the order of litres per day (i.e., tiny relative to pool volume) and cannot be distinguished on a bulk level from normal evaporation at the surface of the pool.

Degradation mechanisms of reinforced concrete affect either the concrete or steel reinforcing materials. They are structure specific and are typically associated with erosion, corrosion or thermal stresses. These aging mechanisms can only be weak in the environment of pure, deionised and cool (< 35°C) water to which the internal surfaces of the structure are exposed. There are no known aging mechanisms that originate from the external surfaces of the structure, which is exposed to slightly humid air at temperature of about 30°C. There are no thermal stress transients associated with different operating states of the reactor or mechanical load transients other than minor load redistributions associated with repositioning of movable reactor bridge. Limited information is available on the effects of long term irradiation on reinforced concrete [6] and no detrimental effects are observed in the available data. In simple terms, no conceivable aging mechanism exists that could cause a catastrophic failure of water retention boundary, which is the nuclear safety topic, under the conditions to which the MNR pool structure is exposed. Any such failure would inevitably be preceded by significant water leakage, which would make the reactor inoperable.

Deterioration of reinforced concretes generally results in cracking, spalling, or delamination of the concrete surface. The structure state and leakage are monitored visually on a routine basis during facilities tours by operations staff. Some limited surface cracking and spalling has occurred in the areas of capillary leakage. The affected surfaces have been repaired by technical specialists. Periodically, maintenance campaigns are undertaken to reduce leak rates by injecting sealants into the pool structure. Maintenance of the pool structure was completed in 2011.The condition of pool structure is deemed to be GOOD on the basis that the capillary leakage is manageable, the outside surface deterioration is minor and repairable, and no mechanism exists to produce a major leakage of safety concern without making the reactor inoperable long beforehand.

4.1.2 Core Structure

Safety Category: Nuclear

The nuclear safety function of the core structure is to provide a stable configuration of fissile materials that facilitates the operation, shutdown and cooling of the reactor core. The MNR core structure consists of the tower assembly, grid plate, plenum and flapper. The first three components are illustrated in Figure 4-1. The flapper is on the back side of the photograph in Figure 4-1. It is schematically illustrated in Figure 2-3.

The core components are primarily constructed of aluminium. A significant database exists on aluminium aging under conditions similar to or harsher than those in MNR. Under MNR pool temperatures, aluminium and its alloys do not corrode in pure water (i.e., in the absence of chloride salts and some other metals). Its yield strength and tensile strength increase with irradiation, while irradiation tends to decrease the ductility of aluminium alloys (e.g., [7]). In simple terms, there are no adverse aging effects on aluminium other than a mechanical 'wear and tear' of moving components or components that interact with moving objects. The only moving component of the core structure is the flapper device. The components in contact with moving objects are the grid plate (infrequent interactions with fuel during core re-configurations) and one face of the plenum (daily interaction with flapper device).

All core components are visually inspected as part of normal shift routine (routine surveillance)[6] as well as during core reconfigurations using binoculars as well as an underwater camera. The flapper device is operationally tested on daily basis.

The condition of core structure is deemed to be GOOD on the basis that there are no adverse aging effects on material properties and no appreciable wear or other signs of damage are observed by surveillance. It is anticipated that improvement of surveillance resolution will permit the reclassification of the condition to very good in the future.

4.1.3 Control Rods and Mechanisms

Safety Category: Nuclear

Control rod is a generic term for a device with neutron absorber. In MNR, these devices are called the shim-safety rods. The shim-safety rod and its associated guide tube are illustrated in Figure 4-2. They are used for coarse power control (process function) as well as for shutdown (safety function). The latter function is accomplished using components illustrated in Figure 2-1. In the context of 'reactor internals', the nuclear safety function (i.e., the reactor trip or scram) is accomplished by four components:

1. The absorber.
2. The control fuel which provides the path for the absorber.

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[6] In an open pool reactor with downward flow, there is a potential for foreign object falling into the pool and obstructing a flow path through the core. Therefore, frequent surveillances of reactor core state are built into the standard operator routine. The frequent observation (several times per shift) facilitates detection of small changes in conditions of core and its structures because there is no long 'memory recall' of previous conditions.

3. The guide tube which encloses the absorber rod extension and protect the extension from impact or interference.
4. The electromagnet which holds the absorber in standby position during operation.

No information was located on aging mechanisms of the absorbers; no degradation of existing absorbers during normal operation is reported in literature. The absorbers were replaced in the 1960s for preventive maintenance reasons. The previous (boron based) absorbers were reported in literature to have a tendency of swelling with advanced age. The existing (silver-cadmium-indium based) absorbers do not have such tendency. The reactivity worth of the absorbers is measured annually. The absorbers are visually inspected during control fuel assembly changes, which are made on ~ five years frequency.

The absorbers are moving devices and they are thus subject to mechanical 'wear and tear'. They are operationally tested daily and the release function of electromagnets is tested at least once per week. Performance tests (drop time tests) are carried out at least quarterly.

The absorber travel path through the control fuel does not experience significant aging. As noted above, the control fuel is replaced on ~ 5 year frequency and the operating experience does not reveal any noticeable degradation of this fuel due to aging.

The guide tube is made of aluminium, the aging properties of which are discussed in Section 4.1.2; there are no adverse aging effects on the aluminium properties. The mechanical 'wear and tear' of guide tubes is acceptable as long as it does not interfere with the drop performance of the absorber. The quarterly performance (drop) tests confirm that there is no detrimental 'wear and tear' of the tubes.

Electromagnet windings operate at slightly elevated temperatures. The winding deteriorates with age. This aging mechanism results in the magnet not being able to pick up the absorber and extension. At this point, the magnet is replaced with a spare and sent for a complete re-build. This is on-demand maintenance. The reactor is inoperable when the electromagnet cannot hold the absorber. No mechanism is known or has been postulated that would prevent the release of the absorber once the electrical power to the electromagnets is cut off. The absorber release provisions (Figure 2-1), which include the electromagnets, are frequently tested by performance tests as noted above.

The condition of safety rods and their associated in-core mechanism is deemed to be VERY GOOD on the basis of results from frequent and diverse surveillances, which are strengthened by the fail-safe features of absorber release function explained in Sections 4.4.1 and 4.4.3.

4.1.4 Beam Tubes

Safety Category: Nuclear

The nuclear safety function of beam tube assemblies is to provide the boundary for the liquid pool (Section 2.1). Two twenty-centimetre (8-inch) diameter and four fifteen-centimetre (6-inch) diameter beam tubes are located in two horizontal planes, passing through the pool structure to point at the reactor core. The basic tube assembly consists of an embedded stainless steel sleeve and a removable aluminium liner (Figure 4-2). A water-tight gasket at the outer face of the pool structure seals the aluminium liner in place. A secondary seal is provided by an aluminium plate at the downstream end of the tube, i.e. outside the pool structure.

Aging mechanisms of liner tube in contact with pool water are discussed in Section 4.1.2; there are no detrimental aging effect related to irradiation or exposure to clean, cool water. The inside environment of the tubes can vary depending on experiment or application. Typically this environment is stagnant air, which is not a corrosive environment. The tubes do not contain moving components and are not exposed to significant mechanical loads. Hence, there is no mechanical 'wear and tear' in the tubes or load induced deformations of the tubes.

The beam tubes are inspected infrequently, typically when maintenance is required on any equipment located within the tube. This is because tube surveillance is potentially a high dose activity and because reactor shut down is required. No signs of damage were observed by past inspections.

Information on aging of stainless steel is available from recent examination of NRU reactor components exposed to more severe radiation fluxes. No detrimental aging effects are observed. Hence, the embedded sleeves are not affected by aging.

The condition of beam tubes is deemed to be GOOD on the basis that there are no aging mechanisms that degrade their safety function of forming a pool boundary. The design compensates for the practical difficulty of surveillance by providing the dual water retention boundary.

4.1.5 Fuel Assemblies

Safety Category: Nuclear

The nuclear safety function of fuel is to provide a dual barrier to release of radioactivity (Section 2.1). The MNR fuel is of the plate type as illustrated in Figure 4-2. The fuel resides in core for ~ 5 years, and spent fuel is stored within the reactor pool for up to ~ 10 additional years before it is shipped off-site for disposal.

No detrimental aging effects have been observed during the MNR operating history. The assemblies are fabricated under strict quality assurance programs and undergo extensive inspection prior to installation in the reactor. Cooling water is continuously monitored for fission products, which would indicate a deterioration of barriers.

The condition of fuel assemblies is deemed to be VERY GOOD on the basis of experience, precautions taken to avoid the installation of defective fuel into the reactor, and continuous surveillance for deterioration of fuel barriers.

4.2 Cooling Systems

4.2.1 Safe Shutdown Configuration of Pool and RCS

Safety Category: Nuclear

This configuration is defined by Figure 2-2. Its nuclear safety function is to passively cool the reactor core at decay power levels. As explained in Section 2.1, the MNR SSCs that accomplish this safety function do not exists in NPPs and are unique in Canada. The passive decay heat removal is accomplished by several different SSCs in IAEA categories.

The pool structure and the beam tubes in Figure 2-2 are covered in Sections 4.1.1 and 4.1.4 respectively. The core structure which provides the natural circulation of pool water through the core shown in Figure 2-2 is covered in Section 4.1.2. Hence, this section pertains to RCS components up to and including isolation valves V1 through V4.

The relevant RCS components involve heavy wall (Schedule 40) piping and stainless steel 'butterfly' isolation valves. The piping is not accessible while the isolation valves are accessible and maintainable; however, a valve access is a high dose activity. These components are not exposed to thermal or mechanical stresses (no fatigue, etc.), do not experience high flow rates (no erosion) and pass through only pure, deionised water (no corrosion). Extensive ultrasonic inspection of identical but accessible piping (i.e., piping beyond the isolation valves discussed in Section 5.1) has shown no indication of wall thinning. Furthermore, their exposures to radiation are modest relative to NRU reactor where the irradiation was found not to degrade the stainless steel properties. The valves are operationally tested in infrequent intervals; there is no scheduled testing of these valves[7].

The condition of the safety essential RCS piping and valves in the non-shaded area of Figure 2-2 is deemed to be GOOD because of the lack of adverse aging mechanisms, occasional testing of the isolation valves and the result of surveillance inspections on accessible piping.

4.2.2 Pool Water

Safety Category: Nuclear

Water is listed in IAEA SSG-10 [4] as relevant component; it is the essential prerequisite of core cooling. From aging standpoint, it is the medium that affects damage mechanisms such as corrosion and erosion in other SSCs. In other words, it has a hysteresis impact on aging of other SSCs.

Given the long operating history of MNR, early records of water conditions are not readily available. Nevertheless, the basic principles of open pool reactor require that high purity, deionised water be used in order to protect workers from radiation hazards associated with water impurities passing through the core and returning into the open pool. This is an additional incentive for maintaining the high purity of water, with implication on real time consequence (and detection) of deviation. The standard incentive of avoiding corrosions and other chemical effects also applies but it does not have real time symptoms, only distant future consequences. Thus, there is a good confidence that water chemistry was closely monitored and maintained at extremely low impurity levels throughout the life of the MNR.

Readily available records confirm that water chemistry is tightly controlled and monitored. Water is continuously purified and losses due to evaporation are made up on demand. On this basis, the condition of pool water is deemed to be VERY GOOD.

4.3 Confinement/Containment

4.3.1 Containment Structure

Safety Category: Nuclear

The containment structure (i.e., the reactor building) is illustrated in Figure 4-3. It safety function is to provide a barrier to release for accidents. The building is constructed on a 1.5

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[7] Valves V-10 and V-12 are used for routine pool isolations and thus operationally tested on essentially daily basis.

meter (five feet) thick, 33 meter (110 feet) diameter (excluding the pump room extension) reinforced concrete slab, contoured to provide this thickness under the reactor pool and various sumps. Under the pump room the pad is not less than 1.07 metres (3.5 feet) thick. The building walls are regular concrete with reinforcing rod; they are 70 centimetres thick at the Experimental Floor level. In addition to structural considerations, this thickness acts as shielding to provide time for warning and evacuation of surrounding areas should a release occur within the building. The roof slabs have a minimum thickness of 30 centimetres, primarily for structural reasons.

Mechanisms of concrete degradation due to aging are discussed in Section 4.1.1. The containment structure is exposed to slightly moist air at ≤ 25°C on the inside and environment on the outside. Both inside and outside surfaces are sealed by protective coatings. Under these conditions, the concrete is stable. Indeed, there are little or no signs of concrete degradation on either surface. The exterior of the structure was refurbished in 2020.

The structure is performance tested annually to ensure the regulatory requirements for leak rate are maintained. During test, it is inspected for signs of damage.

The condition of containment structure is deemed to be VERY GOOD on the basis of surveillance and test results.

4.3.2 Penetrations

Safety Category: Nuclear

There are various penetrations through the containment structure to allow services, equipment and personnel into and out of the reactor building. The safety function of penetration is the same as that of containment structure. All penetrations are inspected annually as part of building leakage test. There are no visible symptoms of damage except corrosion of metal sleeves (i.e., door frames) on one door (West grade door), which is directly exposed to outside environment. A protective exterior structure has been added to shelter this airlock from weather, thus removing the cause of the experienced aging mechanism. Penetration components susceptible to deterioration (e.g., gaskets on doors and hatchway) are routinely monitored and repaired as required by operations staff during routine surveillance, and more extensively inspected prior to the annual leak test.

The condition of containment penetrations is deemed to be VERY GOOD on the basis that, although corrosion of some penetrations is occurring, it is repairable and thus manageable. All penetrations are surveyed both formally and informally and preventive maintenance is performed on any sign of deterioration.

4.3.3 Isolation System

Safety Category: Nuclear

The containment isolation system consists of the two main ventilation isolation dampers (Figure 2-4) which are closed manually or automatically on a high radiation alarm in the exhaust duct. Their safety function is to close on demand and form a barrier to release of radioactivity into the environment.

The dampers are made of cast iron with seal gaskets made of rubber[8]. They are normally closed devices, which are held open by the compressed air pressure. The inlet damper also acts as the control damper. Its opening is regulated by solenoid valves operated by a controller.

The isolation components (i.e., the devices that operate the dampers) are exposed mainly to internal air. These are occasionally moving (i.e., active) devices for which the main aging mechanism (i.e., the 'wear and tear' from repositioning into different operating states) is weak. These devices are tested weekly to ensure a reliable damper actuation.

The open inlet damper, which is by far the most frequent operated state, passes outside air. The open exhaust damper passes moist inside air. A possibility of moisture condensation and attendant corrosion cannot be precluded but these phenomena cannot be pronounced. The dampers are occasionally moving (i.e., active) devices with weak aging mechanism of mechanical 'wear and tear'. They are routinely inspected from the outside (routine surveillance) but their inside surfaces are not accessible for surveillance. There are no symptoms of damage on the outside. The pair of dampers is tested annually for its barrier (i.e. sealing) function (performance testing) as part of the containment leak test.

Both dampers were replaced in 2011 as part of obsolescence management process (i.e., preventive maintenance).

The current status of the isolation SSCs is deemed to be GOOD on the basis of leak test results.

4.4 Instrumentation and Controls

Instrumentation and Controls (I&C)[9] affects all aspects of reactor operation. However, safety-critical I&C devices are those required to bring the reactor into the passive Safe Shutdown State and the devices which warn personnel of abnormal hazards. According to the IAEA SSG-10 [4] hierarchy of topics, the latter devices are covered in separate sections (Sections 4.4.2 and 4.5.1). Thus, the first subsection is to address the I&C used by the three basic safety functions to establish the SSS of the facility (see Section 2.1). Of those three functions, only two employ the I&C devices to establish the SSS. The shutdown function uses such devices to release the absorbers into the core. The containment function uses the I&C devices to isolate the building containment envelope. However, in the IAEA SSG-10 [4] hierarchy of topics, the latter devices are covered in separate sections (Sections 4.4.2 and 4.3.3). Thus, there is only a single topic in the first subsection as given by its heading.

4.4.1 Instrumentation and Controls of Shutdown System

Safety Category: Nuclear

The shutdown system is a subsystem of reactor control system. The components of this system are shown in Figure 2-1. All illustrated components except the electromagnets can be classified as instruments or associated cabling. The electromagnets are covered in Section 4.1.3. The cabling is covered in Section 4.4.3. The safety function of shutdown system I&C is to detect hazardous operating condition and then cut off the electrical power to the electromagnets in order to actuate the reactor trip.

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[8] Ethylene propylene diene monomer (M-class) rubber.

[9] The label 'Controls and Instrumentation' is used in IAEA SSG-10 [4], which is the common label in reverse. The common label is used herein.

Various aging mechanisms come into play, depending on the type of component. The components that deploy contacting surfaces for maintenance or disruption of electrical circuits (e.g., switches, push buttons and relays) are subject to mechanical 'wear and tear' due to changes in operating states. The contacting surfaces are also subject to minor corrosion or oxide build-up as a result of the slightly humid environment. Some of the components (e.g., amplifiers) employ vacuum tubes, which have limited operating life. It should be noted, however, that these aging effect do not impact on the safety function of the instrumentation, only on the reliability of reactor operation. The instrumentation is designed to be fail-safe. It will trip the reactor when any component fails or degrades causing a deviation from the acceptable operating range of a parameter. The reactor is brought into the safe state but is inoperable until the failure or degradation is repaired.

Notwithstanding the fail-safe design, all I&C devices in Figure 2-1 are frequently (daily or weekly) tested and calibrated according to prescribed schedules (scheduled testing). These components are also subject to extensive scheduled inspections (every half hour for some components). The Safety Amplifier is fully performance tested on at least bi-monthly basis.

Every component of the I&C system is currently undergoing a review and replacement on a piece-by-piece basis. Replacement will occur if a component is deemed obsolescent.

The condition of shutdown instrumentation is deemed to be VERY GOOD on the basis of extensive and frequent surveillance and testing, which is backed up by the strong design provisions that safeguard against component or cable degradation or failure.

4.4.2 Radiation Monitoring

Safety Category: Personnel and Nuclear

This equipment consists of area radiation monitors, the Total Iodine Tracking/Airborne radio-Nuclide (TITAN) system, and building and exhaust air particulate monitors. Their safety function is to provide warnings to operating personnel of abnormal radiation hazards in the reactor building (Section 2.2). The exhaust area radiation monitor has a dual safety function. It provides a warning to personnel as well as signals for automatic closure of containment isolation dampers, which is a nuclear safety function. For simplicity and convenience, all radiation monitoring equipment is covered in this section.

These are electronic devices exposed to internal, slightly humid air at moderate temperature (~25°C or less). IAEA SSG-10 [4] indicates that corrosion is the relevant aging mechanism; as noted in Section 4.4.1 minor corrosion or oxide build-up are observed on contacts and junctions by surveillance and are managed by on-demand maintenance. All electronic instruments have life limitations due to obsolescence. They are typically replaceable with modern devices.

All radiation monitors are tested and calibrated according to a maintenance schedule that ensures high reliability of the instruments (scheduled testing and calibration). The air particulate and exhaust monitors were changed in 2005 and the associated recorder for these two monitors was replaced in 2017. The area radiation monitors were changed in 2009 (including cabling) and the previous iodine monitoring system was replaced with the TITAN in 2017.

The condition of radiation monitoring equipment is deemed to be VERY GOOD on the basis of comprehensive testing, calibration, maintenance and obsolescence management programs that are applied to this equipment.

4.4.3 Cabling of Shutdown System

Safety Category: Nuclear

Sound cabling is the prerequisite of all electrical or electronic equipment that needs to operate in order to achieve the passive Safe Shutdown State. This cabling is identified in Figure 2-1. Note that the fail-safe design features of the shutdown system, which are discussed in Section 4.4.1, also apply to the cabling. Any failure or deterioration of shutdown system cables will trip the reactor. Additional explanation of this fail-safe feature is provided in [2] in the context of fire safety. A fire can damage cables in a variety of ways, with the end effect ranging from a short circuit to a deviation in the operating parameters of an electrical circuit. Deterioration of cables by aging mechanisms has the same range of end effects, albeit on a different (slower) time scale.

The prototypical aging damage mechanisms for cables are identified in IAEA SSG-10 [4] as radiation defects, temperature effects and corrosion at junctions. The majority of cables in Figure 2-1 are located such that none of these mechanisms are applicable. The only exception is the cable route to the reactor bridge, where the cables are exposed to very low levels of radiation[10] and the junctions are exposed to elevated humidity levels just above the reactor pool. As described in Section 4.4.1, devices connected to the cables are extensively tested. The frequent absorber functional and performance tests cover the entirety of devices and circuits. The cable route to the bridge is scheduled for replacement in 2012 as a matter of preventative maintenance.

The condition of shutdown system cables is deemed to be GOOD on the basis that the vulnerable cable route is monitored and extensively tested, and that strong design provisions are made to safeguard against cable and component degradation or failure. Very good rating can be assigned to portions of shutdown system cabling that are not located in close proximity of reactor pool.

4.4.4 Other Safety Critical Cabling

Safety Category: Personnel and Nuclear

This other cabling is related to Radiation Monitors in Section 4.4.2 and to containment isolation dampers in Section 4.3.3. None of this cabling is exposed to environments that could cause the aging mechanisms identified in Section 4.4.3. The scheduled testing of radiation monitors in Section 4.4.2 includes the testing of associated alarms and thus testing of associated cable routes. The weekly damper actuation tests in Section 4.3.3 verify that associated cabling is sound. As noted in Section 4.4.2, the upgrade of radiation monitors also includes replacing the associated cabling.

The condition of other safety-critical cables is deemed to be VERY GOOD on the basis that these cables are not exposed to environments that could cause cable deterioration but are nonetheless replaced during equipment and system upgrades and tested for functionality (performance testing).

4.5 Auxiliaries

4.5.1 Fire Protection

Safety Category: Personnel

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[10] The cables are in a location which is frequently accessed by operating personnel.

The fire protection system consists of the detection devices, alarm units and pull stations. Its safety role is to warn personnel of hazardous condition within the reactor building (Section 2.2).

SSG-10 [4] indicates that corrosion might be the relevant aging mechanism. This equipment is extensively monitored by routine surveillance and tested according to maintenance schedule. No symptoms of corrosion (or other degradation) have been observed.

Additional devices were installed in 2010 following recommendations of Fire Hazards Assessment [3]. A complete system upgrade was installed in 2011. These upgrades reflect evolution of fire protection standards.

The condition of fire protection equipment is deemed to be VERY GOOD given that there are no symptoms of aging related deterioration and given the extensive surveillance and testing.

Table 4-1 Conditions of Safety Critical SSCs

	Safety Category	Aging Mechanism	Monitoring of System Health	Refurbishments	Condition
Pool and Reactor Internals					
Pool structure	Nuclear	1, 5, 6	Routine surveillance	On-demand maintenance Major preventive maintenance 2010 Follow-up PR maintenance 2011	Good
Core structure	Nuclear	1, 4	Routine surveillance in pool Operational testing of flapper	On-demand maintenance	Good
Control rods and mechanisms	Nuclear	1, 4, 5	Scheduled performance tests Routine surveillance in pool	On-demand maintenance	Very Good
Beam tubes	Nuclear	1, 5	On opportunity inspection	BT 5 replacement 2013, BT 4 replacement 2022	Good
Fuel assemblies	Nuclear	1, 5	Pre-installation inspections Monitoring of H_2O radioactivity Routine surveillance in pool	Replaced ~ every 5 years	Very Good
Cooling Systems					
Safe shutdown configuration of pool and RCS	Nuclear	1, 4, 5, 6	Operational tests of valves Routine surveillance		Good
Pool water	Nuclear		Scheduled testing	On-going purification & make-up	Very Good
Confinement/Containment					
Containment structure	Nuclear	5	Annual performance testing Routine surveillance	On-demand maintenance Exterior refurbishment 1995, 2020	Very Good
Penetrations	Nuclear	5	Annual performance testing Routine surveillance	On-demand maintenance West grade refurbishment 2010	Very Good
Isolation system	Nuclear	4, 5	Weekly actuation testing Annual performance testing Routine surveillance	On-demand maintenance Isolation damper replacement 2011	Good

	Safety Category	Aging Mechanism	Monitoring of System Health	Refurbishments	Condition
Instrumentation and Controls					
C&I of shutdown system	Nuclear	4, 5, 8	Scheduled testing & calibration Routine surveillance	On-demand maintenance	Very Good
Radiation monitoring	Both	5	Scheduled testing & calibration Routine surveillance	On-demand maintenance Replaced particulate air monitors in 2005 Replaced ARMS in 2009 Replaced iodine monitoring system in 2017	Very Good
Cabling of shutdown system	Nuclear	1, 5, 6	Operational testing	On-demand maintenance	Good
Other safety critical cabling	Both		Operational testing	Replacement on opportunity	Very Good
Auxiliaries					
Fire protection	Personnel	5	Scheduled testing & calibration	On-demand maintenance Equipment added 2005 Equipment added 2010	Very Good

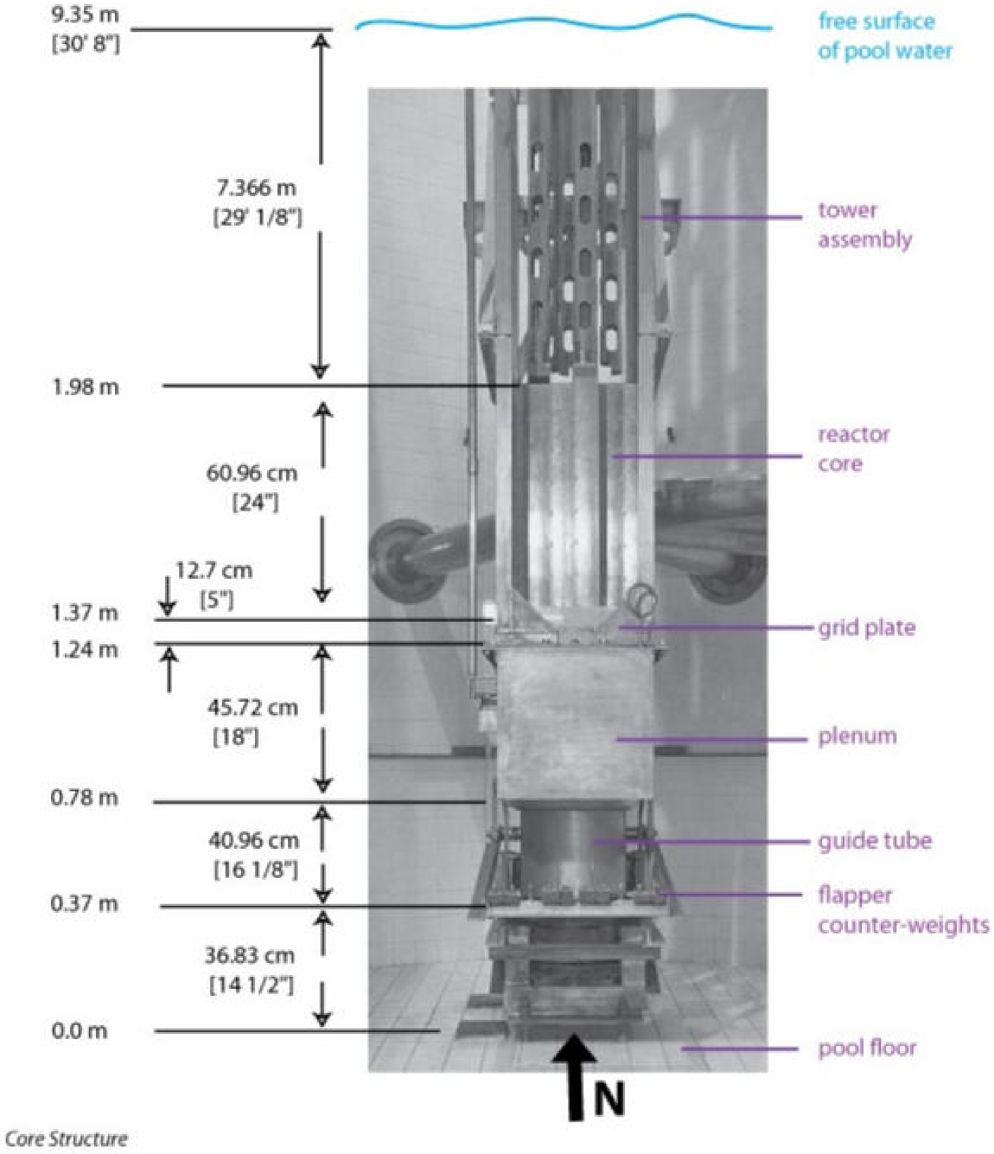
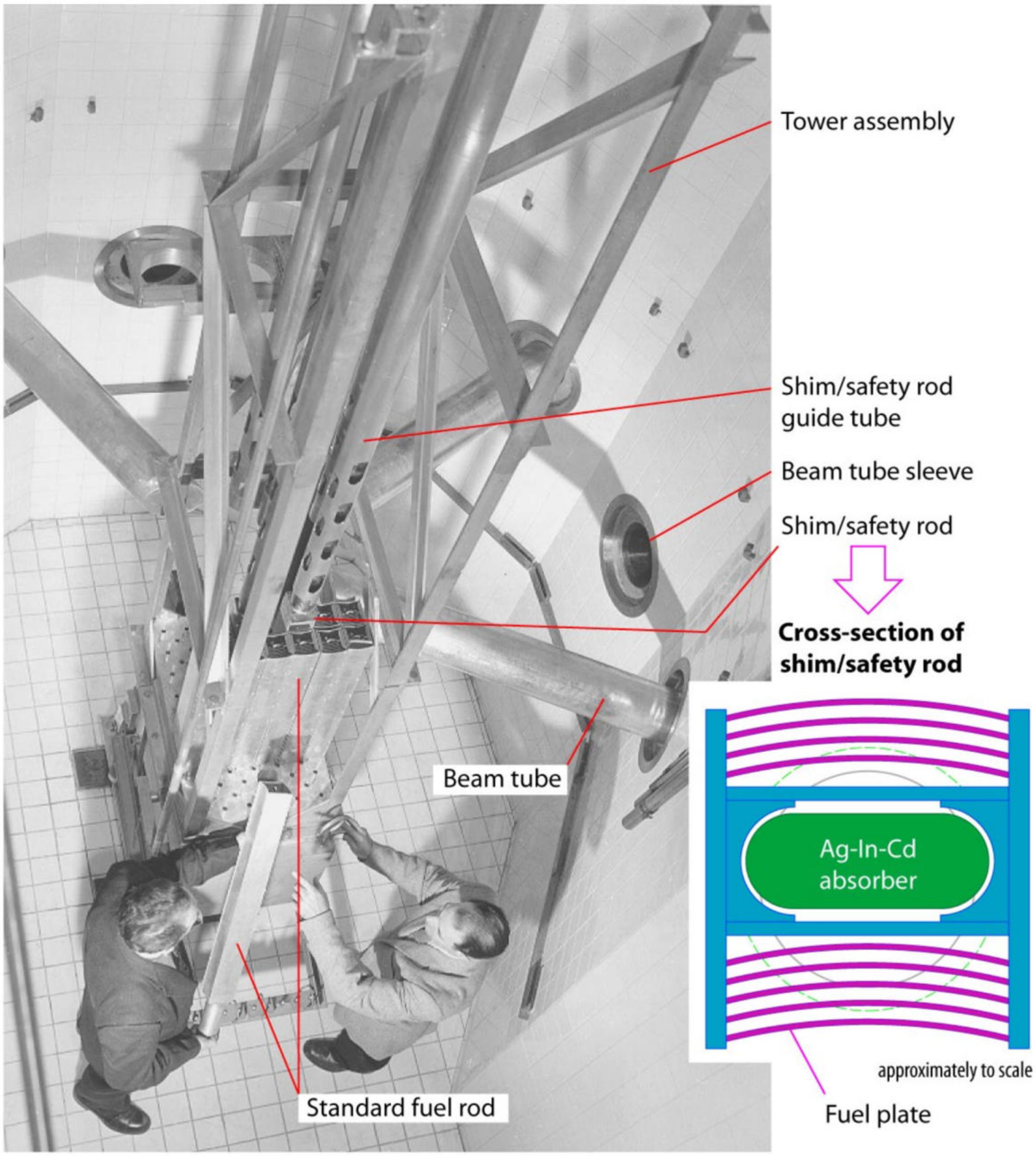


Figure 4-1 Components of Core Structure



Safety Rod

Figure 4-2 Shim-Safety Rod and Reactor Structures

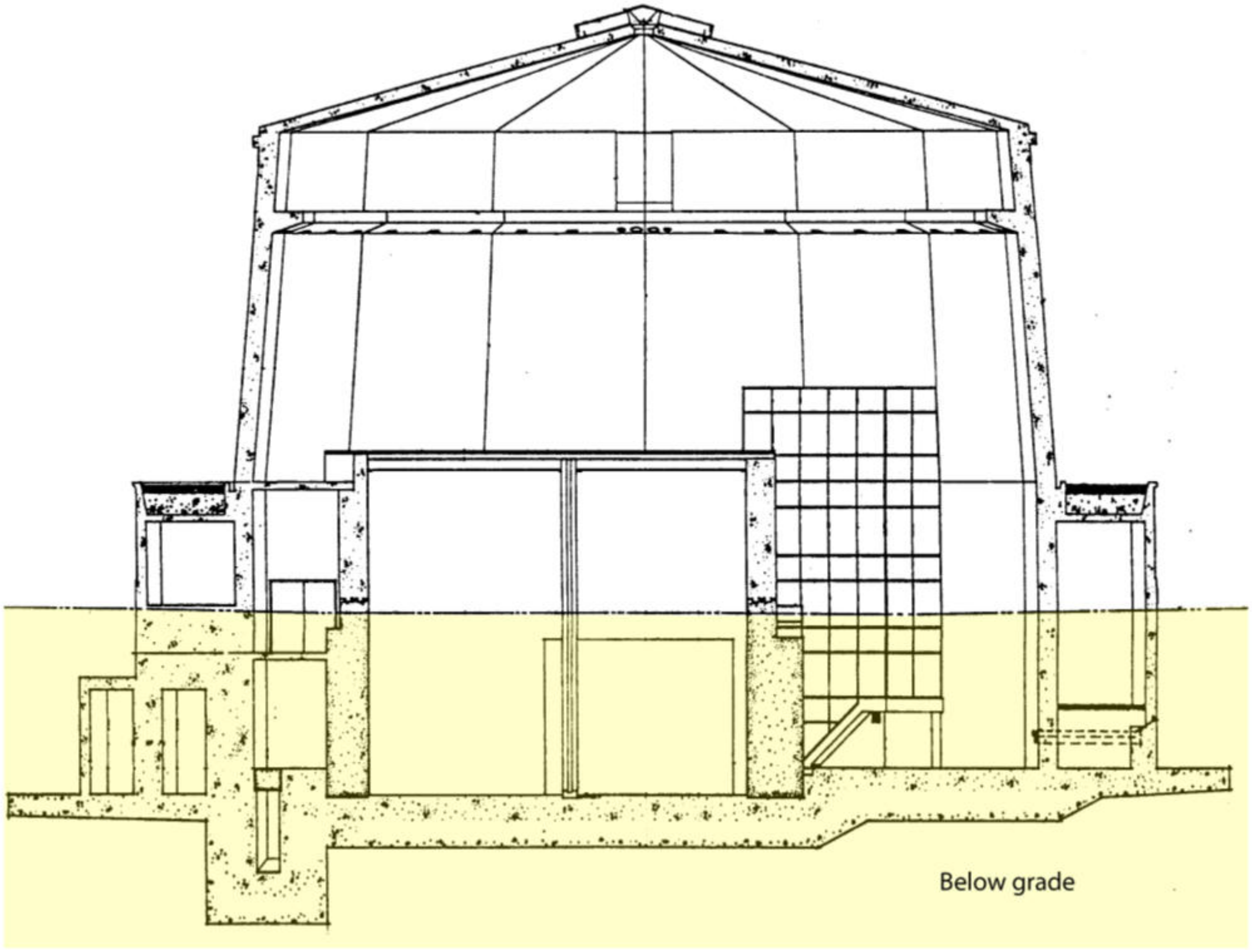


Figure 4-3 Reactor Building North-South Cross Section

(From Figure 4-3 in [8])

5. OTHER SSCS AND THEIR CONDITION

The MNR has a number of other SSCs which are not required to achieve a Safe Shutdown State of the reactor, and which do not provide warnings of abnormal hazards to personnel. These other systems nonetheless provide defence in depth for safe and reliable operation of the reactor. SSCs, which are important for defence in depth are listed in Table 5-1 and discussed in this section.

5.1 Cooling Systems

SSCs in this category include:

- The RCS components in the shaded area of Figure 2-2;
- The purification system that maintains the primary coolant within prescribed limits in terms of water level and composition; and
- The secondary water cooling system (Figure 5-1) that provides the external heat sink during high-power operation of the reactor.

The process functions of RCS components beyond the isolation valves are to transport the core heat to the heat sink and to protect personnel from occupational exposure to short-lived activation products generated by water passing through the core. This latter function is passively achieved by delay in the Hold-Up Tank (HUT) (Figure 2-2). These components also provide water retention barriers for an alternate Safe Shutdown State in which the isolation valves remain open. The latter is not the designated SSS but is also passive and equally effective as explained in [2]. Thus, the RCS boundaries in the shaded area of Figure 2-2 are backup boundaries. Components of purification and secondary cooling systems do not participate in the SSS; they and only process components.

All metal components on the primary side of these cooling systems are made of stainless steel; the secondary cooling system contains carbon steel. All components are exposed to mild service conditions (i.e., low pressure, low temperature and low radiation fields). Thus relevant aging mechanisms are the mechanical ‘wear and tear’ on moving components (e.g., pumps) and the corrosion or erosion of metals, which is more likely for the carbon steel in the secondary water circuit.

Concrete vessels in this category of systems (i.e., HUT and Storage Tank (ST) in Figure 2-2) are similar to the pool structure in Section 4.1.1 but are epoxy lined instead of tiled. Scheduled inspections of the HUT and the ST have revealed no appreciable deterioration.

Continuous monitoring and analysis of RCS flows and temperatures provides ongoing indication of RCS health in terms of heat removal capacity. A slow trend of decreasing flow rate was identified and monitored, which led to preventive maintenance in 2005 and 2008 to remove deposits on the primary side of the heat exchangers. This maintenance restored the system flows to essentially ‘as built’ values. The RCS components in the greyed area of Figure 2-2 are accessible and are subjected to routine surveillance as well as annually tested by non-destructive techniques (ultrasonic and/or eddy current inspections). No appreciable deterioration of water retention barriers was found except on the secondary side of the heat exchanger tubes where the microbial corrosion was indicated. In accordance with good engineering practices, the most affected tubes were removed from service (i.e., plugged) in 2010. Successive biennial inspections have continued to identify tubes with corrosion which have been plugged since. The heat removal capacity required for full power operation is maintained since the heat exchangers have a built-in excess heat transfer area. Moving components are operationally tested and subjected to routine surveillance and scheduled maintenance.

Given the manageable existence of aging effects, the condition of RCS beyond isolation valves is deemed GOOD.

Continuous monitoring and analysis of water purity and levels provides ongoing indication of purification system health. Surveillance of the purification system identified corrosions in carbon steel tanks that hold the ion-exchange resin. One of the tanks was replaced with stainless steel tank in 2007 and the remaining tank was replaced in 2010.

Local corrosion in the purification system was prevented by the replacing vulnerable carbon steel components with stainless-steel components. Demineralizer pumps and piping surrounding the pumps were replaced in 2021. Given that corrosion in now greatly reduced, and that surveillance and testing continues, the condition of purification SSCs is deemed to be VERY GOOD.

The secondary cooling system transfers heat from the primary side of the heat exchanger to the cooling towers by conduction through the secondary tube walls. This system uses city water (with pH control and algae inhibitors). The secondary side of the heat exchanger is a bank of tubes within each of the two exchangers; a two-pass configuration is used in each heat exchanger. The cooling towers are located outside the Reactor Building and were replaced in 1999. The piping, valves and pump associated with the secondary system were replaced in 2011

The condition of secondary cooling system is deemed GOOD on the basis that aging phenomena are managed by timely maintenance.

The overall conditions of systems in this category are rated in Table 5-1. All SSCs are accessible for surveillance and are monitored and tested. Minor mechanical ‘wear and tear’ of moving components is occurring and is operationally tested and subjected to routine surveillance and scheduled maintenance. Corrosion of secondary water cooling circuits is managed by chemistry control, routine surveillance and scheduled maintenance and inspections.

5.2 Confinement and Containment Systems

SSCs in this category include:

- The ventilation system’s air handling equipment and ducts located within the containment envelope (i.e., within the red boundaries of Figure 2-4).
- The sump system’s liquid handling pumps, piping and reservoirs located as shown in Figure 5-2.

These SSCs are not necessary to achieve SSS of the facility, but do affect reactor operability and occupational exposures of personnel.

The ventilation SSCs are exposed to inside air. The main aging mechanisms for these SSCs are mechanical ‘wear and tear’ of rotating equipment (e.g., fans and motors) and the condensation-related formation of deposits on (and possible corrosion of) the Reactor Hall Unit (RHU) cooling coils. The RHU re-circulates building atmosphere and serves as the air conditioner for the building. The equipment is accessible except for duct internals. Routine surveillance is performed on all equipment; duct inspection is performed when an opportunity arises to examine inside surfaces. Air properties (temperature, humidity, flow) are continuously monitored. Air temperatures can be maintained within acceptable range. Air flows through the various flow paths are normal; this confirms that aging has not affected the performance of fans or the hydraulic properties of flow paths. The RHU and fans were replaced 2011.

The sump SSCs are exposed to active water, possibly contaminated by various substances found on the floors of industrial facilities. Sump piping and pumps were replaced in 2010.

The overall condition of SSCs in this category is GOOD. Although mild symptoms of aging degradation are present in some components, the assessment is that no performance deterioration or failures are imminent.

5.3 Instrumentation and Controls

The SSCs in this category include:

- The reactor control system as illustrated in Figure 5-3. Note that the shutdown system discussed in Sections 4.4.1 and 4.4.3 is a subsystem of the control system. Only SSCs that perform process control functions of the control system are discussed in this section.
- Instruments that provide signals to trigger various annunciations and control system actions or provide essential information on the state of the reactor.

The SSCs of the control system are exposed to the same aging mechanisms, and are subject to the same rigorous and frequent surveillance and testing, as the shutdown subsystem described in Section 4.4.1. On-demand maintenance is performed upon any indication or suspicion of deviation from normal performance. A component review and replacement of the entire I&C system is currently ongoing.

Instruments related to the control system include the detector chambers identified in Figure 5-3 as well as the instruments that provide the so-called safety interlock signals that are identified in the second shaded block from the top of Figure 2-1. Two of the safety interlock signals are provided by RCS instruments (the Fission Product Monitor (FPM) and the Core Flow meter) discussed below. The rest are provided by electro-mechanical devices (switches, relays). Comprehensive testing and calibration of equipment in this group is performed at least monthly with a subset of these instruments included in weekly routine. Daily verification of availability and normal performance of control system equipment is performed prior to reactor start-up.

The RCS instruments provide information on flow, temperature, and activity of the coolant. They are important for diagnosing and monitoring reactor operation. Trends are recorded and analysed, permitting assessment of RCS performance. They are calibrated on a prescribed schedule. New DP cells have been added in parallel to the existing systems. They provide signals for the new recorders installed in 2016. All DP cells are regularly checked for operation and calibrated annually. All RTDs are calibrated annually and replaced on an as needed basis.

The overall condition of SSCs in this category is rated as GOOD. Mechanical ‘wear and tear’ of switches, relays, mechanical recorders, etc., it is managed by extensive surveillance and testing in conjunction with on-demand maintenance. There are no indications of aging deterioration on chambers, orifice flow meter, RTDs or the FPM. These instruments are tested and calibrated. They are being replaced as appropriate for reasons of obsolescence.

5.4 Auxiliary Systems

SSCs in this category include:

- The main building crane; and
- The electrical systems.

These SSCs are not needed to achieve SSS of the facility. They provide non-nuclear services and must be kept in good working order in order to avoid hazards to personnel and damage to systems which they serve, and to maintain operational efficiency.

The aging effects on the crane are mechanical 'wear and tear' and corrosion. No symptoms of corrosion have been observed. As part of sound operating practice, surveillances of the crane for changes of conditions are continuously performed by operating personnel. Annually, thorough inspections are completed by third party contractors. Preventive and on-demand maintenances are also performed (e.g., greasing/oiling). The crane cable was replaced in 2010 and a major refurbishment of crane mechanical and electrical components was completed in 2011. These are preventive maintenance activities.

The electrical equipment is subject to a number of aging effects ranging from mechanical 'wear and tear' of moving components[11] to chemical effects such as corrosion in junctions, which in turn can lead to thermal anomalies and their associated aging effects[11]. Routine surveillance is carried out by operating personnel and on-demand testing (thermal imaging) of component assemblies and circuits has also been performed. No anomalies were found. The Main Motor Control Centre and the two main Lighting Power Panels were replaced in 2011 as part of obsolescence management. Upgrade of backup power supply was completed in 2012.

The overall condition of SSCs in this category is GOOD. Mild symptoms of aging are present, which are being managed by preventive maintenance and obsolescence management activities.

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[11] This aging mechanism is not noted as relevant for electrical systems in IAEA SSG-10 [4].

Table 5-1 Conditions of Other SSCs

	Aging Mechanism	Monitoring of System Health	Refurbishments	Condition
Cooling Systems				
RCS components beyond isolation valves	1, 4, 5, 6, 7	Annual non-destructive testing Routine surveillance Operational testing	Scheduled & on demand maintenance HX scale removal 2005 & 2008 Pump & check valve replaced 2011	Good
Purification system	1, 5	Scheduled H_2O parameters testing Routine surveillance Operational testing	Scheduled & on demand maintenance Demin tanks replaced 2007, 2010 Pumps & piping replaced 2021	Very Good
Secondary water systems	4, 5, 6, 7	H_2O parameters testing Routine surveillance Operational testing	Scheduled & on demand maintenance Cooling towers replaced 1999 HX tube NDT and isolation biennially Piping, valves & pumps replaced 2011	Good
Confinement/Containment				
Ventilation systems	4, 5, 6	Air parameters testing Routine surveillance Operational testing	Scheduled & on demand maintenance HVAC and fans replaced 2011	Good
Sump systems	5	H_2O parameters testing Routine surveillance Operational testing	On demand maintenance	Good
Instrumentation and Control				
Control system	4, 6, 8	Scheduled testing & calibration Routine surveillance Operational testing	On demand maintenance	Good
RCS Instrumentation	1, 6	Scheduled testing & calibration	RTDs calibrated annually, replaced when failed 2nd flow transducer & recorder added 2009 FPM replaced 2018	Good

	Aging Mechanism	Monitoring of System Health	Refurbishments	Condition
Auxiliaries				
Cranes	4, 5	On-demand and scheduled testing Annual 3rd party inspections	Scheduled & on demand maintenance Cables replaced 2010 Major refurbishment 2011	Good
Electrical Systems	6, 8	Routine surveillance	On demand maintenance Main MCC and LPPs replaced 2011 Backup power replaced 2012	Good

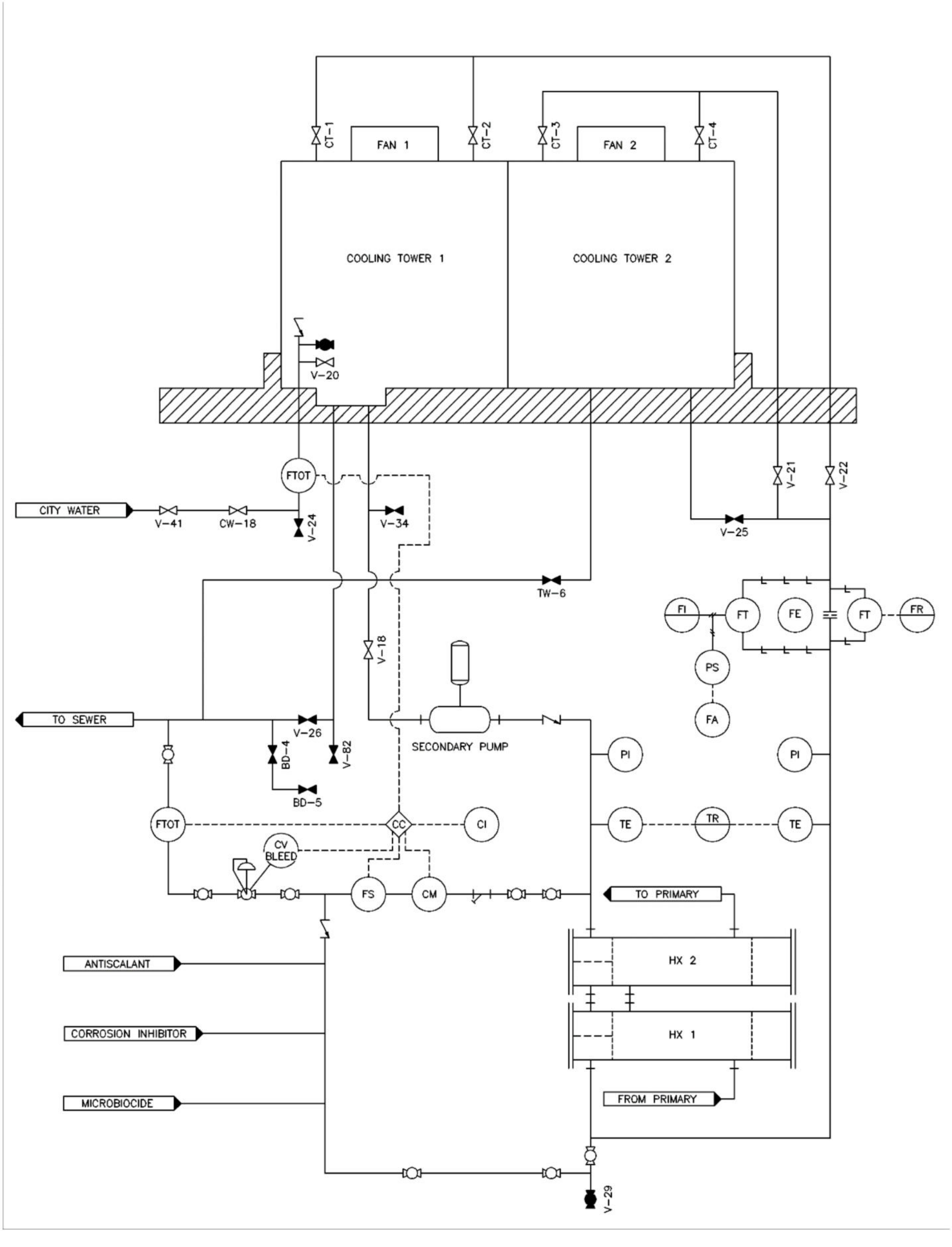

Figure 5-1 SSCs of Secondary Water Cooling System
(Figure 6-3 in [8])

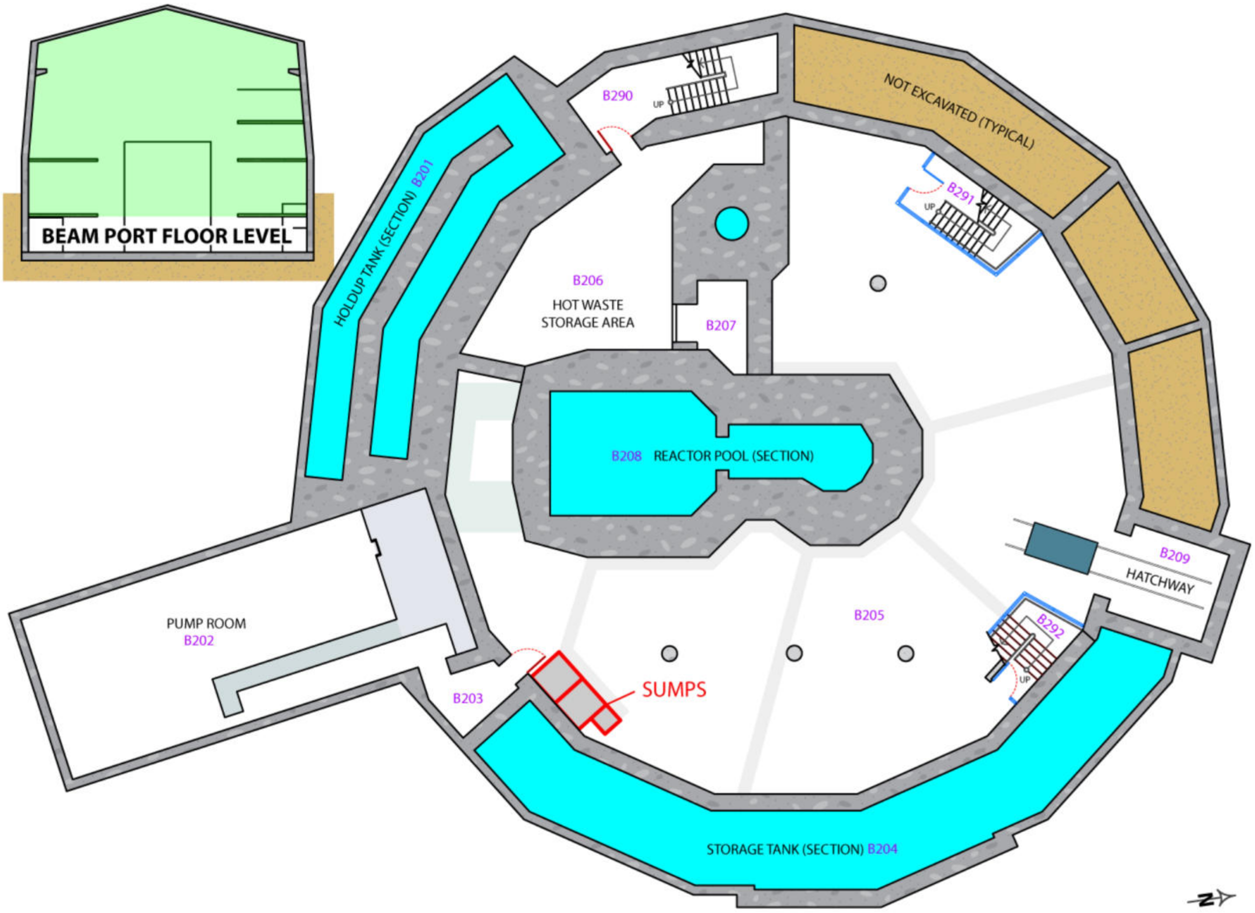

Figure 5-2 Active Sumps Location

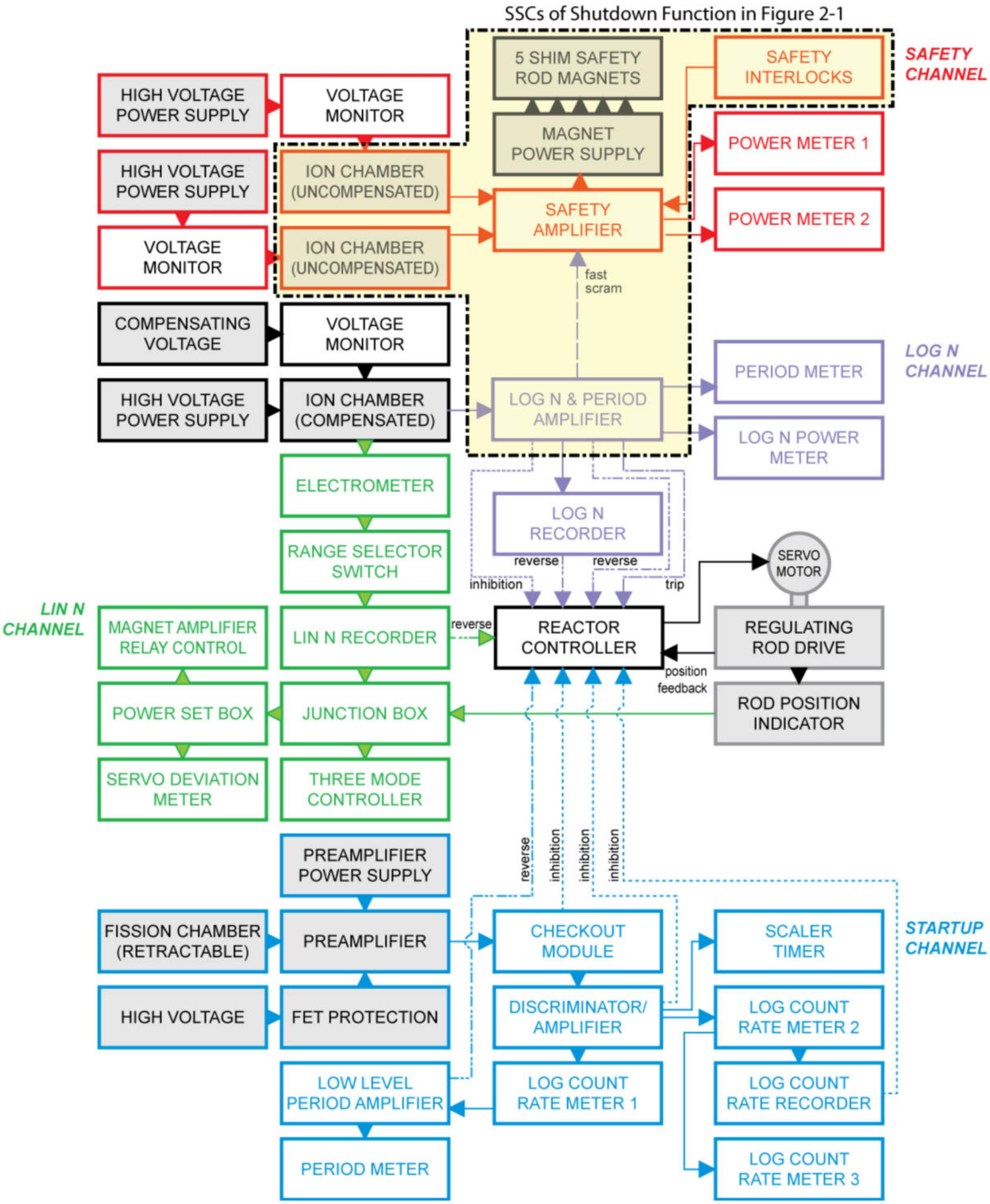

Figure 5-3 SSCs of Control System

6. CLOSING REMARKS

This report compiles information on the present conditions of structures, systems, and components (SSCs) in McMaster Nuclear Reactor (MNR) with consideration of aging effects.

The report categorizes the MNR SSCs, identifies those which are safety-critical and explains why these SSCs are safety-critical.

The report assesses the condition of the SCCs based on actual condition, surveillance, preventive maintenance and obsolescence and aging management measures in place and scheduled at the facility.

The overall conclusion of the report is that safety-critical SSCs at MNR are all acceptable with identified and scheduled activities in place to move many of the condition assessments from a "GOOD" rating to a "VERY GOOD" rating.

MNR is continuously reviewing and monitoring SSCs as a part of the refurbishment program at the facility (see Table 4-1 and Table 5-1), it is recognised that aging management is an on-going process. MNR incorporates the information documented in this report to review, guide and support future aging management strategies.

7. REFERENCES

[1] Letter N. Riendeau to C.J. Heysel, "Inspections, Maintenance and Aging Management for the McMaster Nuclear Reactor", October 19, 2010; CNSC file 4.03.02.

[2] C. Blahnik, "Fire Safe Shutdown Analysis of McMaster Nuclear Reactor", MNR TR 2009-01, Rev. 1, 28 February 2010.

[3] G. Qamheiah, "McMaster Nuclear Reactor - Fire Hazard Assessment", Rev. 0, March 31, 2010.

[4] IAEA, "Aging Management for Research Reactors", Specific Safety Guide No. SSG-10, 2010.

[5] T .G. Theofanous, "Dealing with Phenomenological Uncertainty in Risk Analysis", Plenary Lecture in Workshop I in Advanced Topics in Reliability and Risk Analysis, Annapolis, MD, October 20-22, 1993, NUREG/CP-0138, October 1994

[6] C.B. Oland and D.J. Naus, "Summary of Materials Contained in the Structural Materials Information Center", ORNL/NRC/LTR-94/22 (Oak Ridge, TNL Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, November 1994).

[7] U.S. Department of Energy, "DOE Fundamentals Handbook - Material Science", Volume 2, DOE-HDBK-1017/2-93, January 1993.

[8] McMaster Nuclear Reactor Safety Analysis Report, February 2002.