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Mémoire de Paul Sedran, RESD Inc.

In the Matter of

À l'égard de

McMaster University

Université McMaster

Application to renew its McMaster Nuclear Reactor Class IA non-power reactor operating licence

Demande concernant le renouvellement de son permis d'exploitation d'un réacteur de catégorie IA non producteur de puissance pour le réacteur nucléaire McMaster

Public Hearing - Hearing in writing based on written submissions

Audience publique - Audience fondée sur des mémoires

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Fitness-for-Service Review for the Control Rods of the McMaster Nuclear Reactor

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1. Introduction

McMaster University currently holds a ten year Class IA non-power reactor operating license for the McMaster Nuclear Reactor (MNR), which was issued on July 1, 2014, and will expire on June 30, 2024.

In addition to operating as a research reactor, the MNR has been producing various medical isotopes including iodine-125 and holmium-166 since 2001, which are crucial for medical treatments.

In order to continue the vital operation of the MNR, McMaster University has submitted an application to the CNSC for a renewal of the MNR operating license for an additional 20 year period to 2044, documented in Reference [1]. Included with the application, McMaster has submitted a technical report on the fitness-for-service of the MNR, Reference [2]. As part of the review of McMaster's application, CNSC technical staff have submitted a review of the licensing application in Reference [3] and will be conducting a public hearing for the MNR license renewal, scheduled for April, 2024.

Under Contribution Agreement reference number: PFP 2023 MNR-01, the CNSC has funded the author to review the text of References [1] – [3] pertaining to the fitness-for-service of the control rod and guide tube of the MNR.

A brief review of control rod structural fitness-for-service is summarised in this document as well as an independent assessment of the functional fitness-for- service (insertion and retraction of the control rods).

Although the assessment has a narrow focus on a specific area, it does support the case for continued operation of the MNR to 2044.

2. Reviewed Documents

The following documents were reviewed.

1. Reference [1]: McMaster University, Non-Power Operating Licence Renewal Application, April 2023.

2. Status of McMaster Nuclear Reactor Structures, Systems, and Components, MNR Technical Note TN 2010-04, Revision 1, 10 April 2023

3. CNSC CMD: 24-H100.A, A Licence Renewal, McMaster Nuclear Reactor, February 16, 2024.

3. Description of the Guide Tube and Control Rod

Figure 1, provided by McMaster Nuclear Operations in Reference [4], shows a cross-section of the MNR Control Rod. The absorber cross-section consists of an oval-shaped hollow shell with a transverse length, X, of 2.25 in, and a transverse width of 0.88 in. The thickness of the shell, which is made of an alloy of silver-cadmium-indium, (Ar-Cd-In), is 0.125 in.

It is believed that the absorber element has a thin nickel-tin sheathing to prevent corrosion of the absorber by the coolant.

During operation of the MNR, the Control Rods are stored above the reactor inside the Control Rod Guide Tubes, under minimal fast neutron flux. To initiate a reactor shutdown, the Control Rods are lowered through the Guide Tubes and into spaces in the centre of each fuel bundle in the reactor core.

Figure 1
Cross-Section of the MNR Control Rod

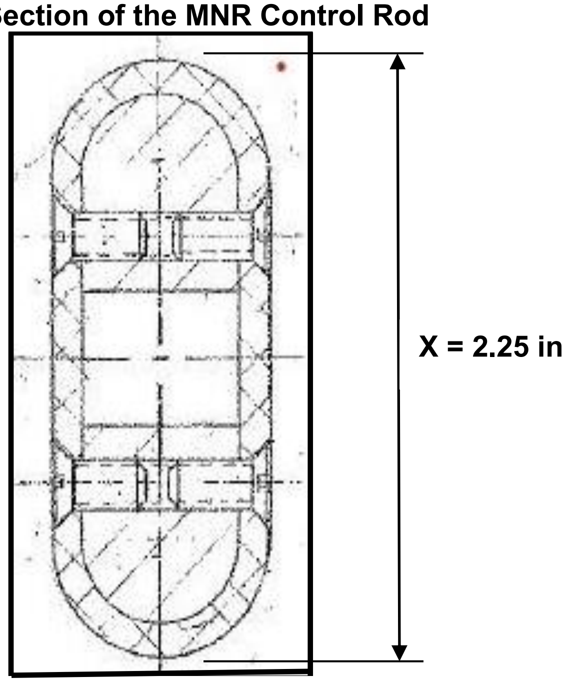
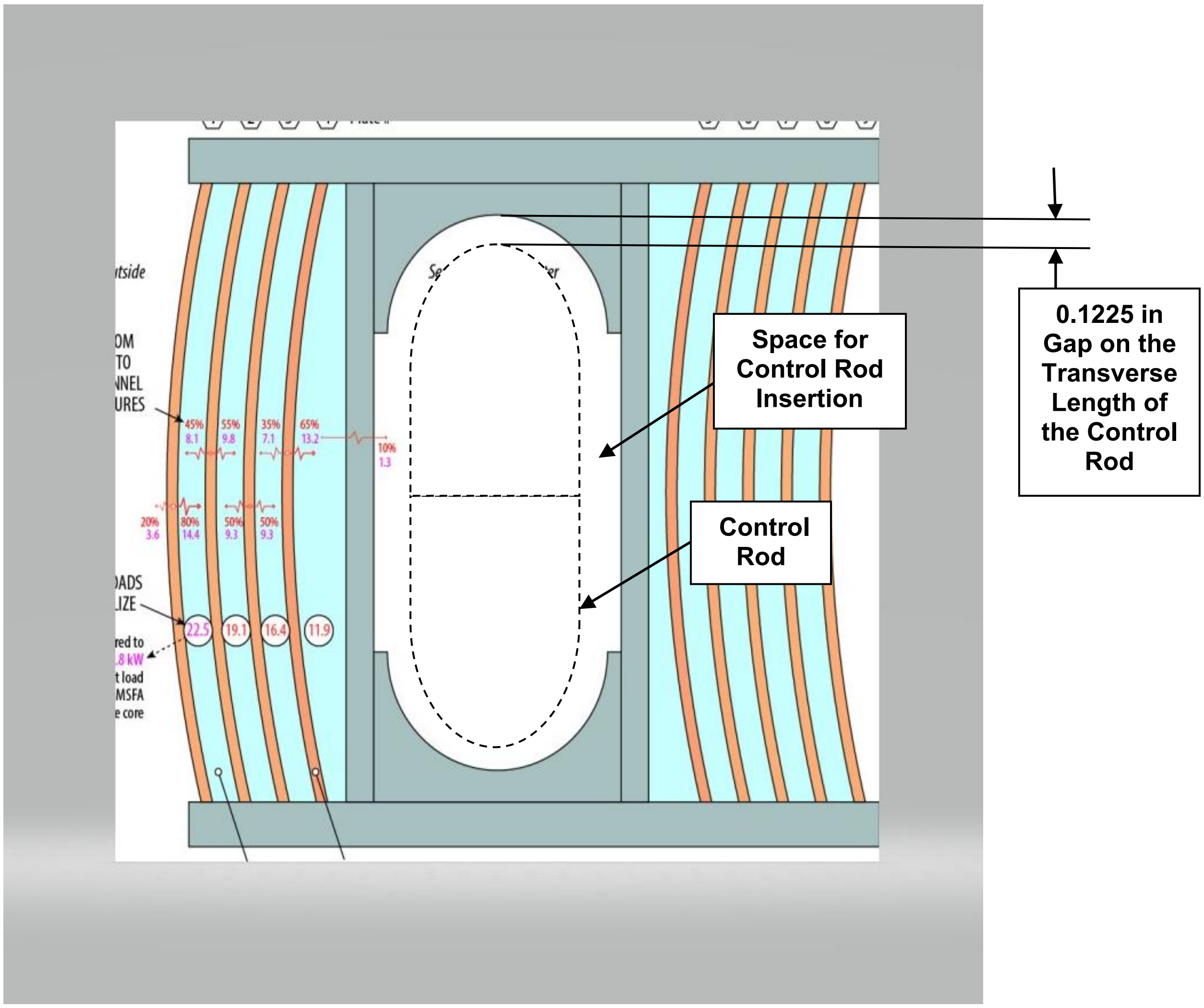


Figure 2 depicts a cross-section of a fuel bundle in MNR, noting that the Control Rod is inserted into the oval-shaped space at the centre of the Bundle.

It should also be noted that when the Control Rod is inserted into the Fuel Bundle, the nominal gap between the outside of the absorber at the maximum transverse length and the corresponding point on the Fuel Bundle is 0.1225 in. The gap in question is illustrated in Figure 2, which shows an outline of the outside of the cross-section of the Control Rod inside the Fuel Bundle.

Figure 2
MNR Fuel Bundle



4. Fitness-for-Service Assessment for the Control Rod

The potential threats to the proper functioning of the Control Rods (the functional fitness-for-service), in order of severity, are:

1. Severe structural degradation of the absorber material, leading to cracking, loss of absorber material, and a reduction in Control Rod worth.
2. Irradiation induced swelling of the absorber material, leading to interference of the Control Rod with the Guide Tube or the Fuel Bundle.
3. Irradiation and/or thermally induced bowing of the Control Rod, leading to interference of the Control Rod with the Guide Tube or the Fuel Bundle.

An assessment of absorber material degradation is presented in Section 4.1. Section 4.2 covers an assessment of absorber material swelling and Section 4.3 provides an assessment of Control Rod bowing.

4.1 Structural Degradation of the Absorber Material in the Control Rod

Historically, structural degradation of the absorber element is the most severe threat to the fitness-for-service of a Control Rod. In the most severe case, it consists of the loss of material from the neutron absorbing element of the Control Rod, caused by:

1. Swelling of the absorber material due to the absorption of neutrons,
2. Cracking of the irradiation-embrittled Control Rod Sheath from the expansion of the absorber
3. Ingress of coolant into the Control Rod
4. Corrosion of the absorber material leading to absorber swelling and the leaching of absorber material
5. Macroscopic cracking and absorber expansion, leading to fish mouth opening of the Sheath and the egress of pieces of absorber material from the Control Rod.

The fitness-for-service assessment of the MNR Control Rods was performed from the perspective that Scenarios 1-5, although very unlikely, could possibly occur in the future.

4.1.1 Assessment of Absorber Material Structural Degradation

A point to be noted at the start of the assessment is that Scenarios 1 – 5 were experienced in PWRs and BWRs with typical operating thermal powers of 1000 MW, compared to the much lower power of the MNR, which generates a thermal power of 5 MW. On this basis, it was reasonable to expect that irradiation-induced damage to the MNR Control Rods should be proportionately lower than that observed in PWRs and BWRs.

Estimations of the current volumetric swelling of the absorber element and the corresponding strain in the Control Rod Sheath are provided in Section 4.2. The strain in the Sheath is judged to be insufficient for the Sheath to have cracked. Therefore, presently, the severe damage of Scenarios 1 – 5 can be ruled out.

The on-going structural integrity of the Control Rods has been confirmed through the following various means, from Reference [3]:

1. Visual inspections of the Control Rods for damage to the Sheath, performed approximately once in five years – no damage was noted in the reports.
2. Annual measurements of the reactivity worth of the Control Rods, indicating no macroscopic damage to the Control Rods.
3. Quarterly drop time testing of the Control Rods, indicating no increase in drop time that would signal damage to the Sheath.

4.2 Swelling of the Neutron Absorbing Material in the Control Rod

Reference [2] was found to contain the following text:

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 statement that the silver-cadmium-indium (Ar-Cd-In) neutron absorbers in the MNR would not undergo swelling appeared to be inconsistent with the history of control rod degradation in Pressurized Water Reactors (PWRs) and Boiling Water Reactors (BWRs), in which absorber swelling was a factor.

Based on PWR and BWR control rod OPEX, above, and the fundamentals of neutron absorption, the reviewer suspected that the Ar-Cd-In neutron absorbers in the MNR must be undergoing swelling as a result of neutron irradiation.

A brief search was conducted on the material behaviour of Ar-Cd-In under neutron irradiation. References [5] and [6], two of several available references, state that Ar-Cd-In neutron absorbers in power reactor control rods were subject to swelling. It is acknowledged that the original boron carbide control rods in the MNR were subject to more swelling than the current silver-cadmium-indium control rods. However, the fitness-for-service assessment of Reference [2] is technically incorrect in stating that the neutron absorbers in the current MNR control rods have no tendency to swell.

Swelling of the Ar-Cd-In absorber material under neutron irradiation is caused by the transmutation of Ag into Cd and of In into Sn, thereby increasing the volume of the absorber. With further production of Sn, the solubility limit of Sn in solid solution would be exceeded and it would precipitate out of solution, causing further swelling of the absorber, which can lead to cracking of the control rod Sheath.

4.2.1 Approximate Calculation of the Rate of Control Rod Swelling

An approximate calculation of the rate of swelling of the MNR Control Rod was performed, assuming that the measured rate of Ar-Cd-In absorber swelling from Reference [6] (% volume per unit fluence) is representative of that in the MNR.

Figure 2, on the next page, from Reference [6], provides measured volumetric rates of swelling versus fast neutron fluence for Ar-Cd-In absorber material. For the swelling rate calculation, the “Maximum Law” of Figure 2 was used.

A summary of the calculation is presented in Table 2, also on the next page. A definition of the nomenclature in the headings of Table 2 appears below the table.

The table provides the calculated current average fluence for the Control Rod and the resultant current percentage of swelling of the absorber element, assuming 60 years in-service. The right-hand column of the table provides an estimate of the current elongation of the cross-section of the Control Rod in the transverse direction (in the direction of X in Figure 1) that is associated with swelling of the absorber element.

Figure 2
Measurements of Volumetric Swelling vs Fast Neutron Fluence
For Ar-Cd-In Absorber Material

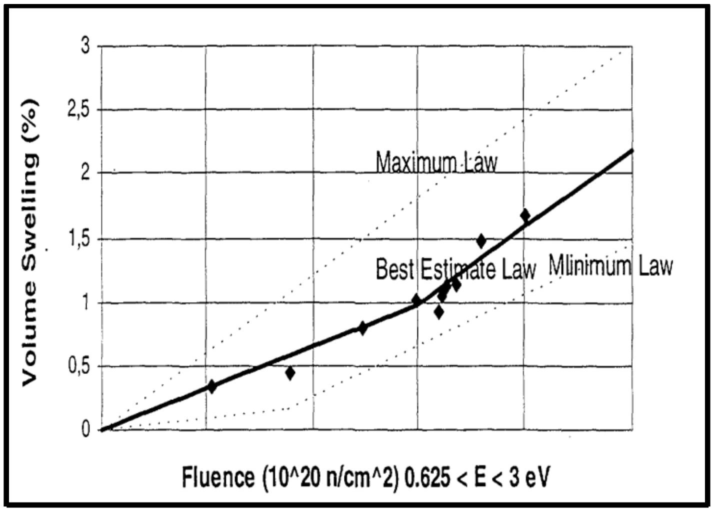


Table 2
Estimation of the Current Lifetime Fast Neutron Fluence, Swelling, and Transverse Elongation of the MNR Control Rod Absorber

SD Duration	SD/y	t in Flux/y	Average Flux	Average Fluence/y	Years IS	Average Fluence	%ΔV	% Δx	X	Δx
(s)		(s)	(n cm^{-2} s^{-1})	(n cm^{-2})	(y)	(n cm^{-2})			(in)	(in)
120	208	24960	1.00E+13	2.50E+17	60	1.50E+19	0.045	0.356	2.25	0.008

Definition of Headings in Table 2

SD Duration – Shutdown Duration

SD/y – Shutdowns per year

t in Flux/y – Time spent in flux per year

Average Flux – Average Fast Neutron Flux

Average Fluence/y – Average Fast Neutron Fluence per year

Years IS -Years in-Service

Average Fluence - Average Fast Neutron Fluence

%ΔV – Percentage increase in volume due to swelling

% Δx – Percentage transverse elongation due to swelling

X – Transverse length of the Control Rod Absorber

Δx – Transverse elongation due to swelling

For the fluence calculation, the average operating flux over the Control Rod was taken from Reference [7]. The SD duration represents a conservative estimate for the time that the section of the Control Rod at average flux would experience flux during each shutdown, from

Reference [8]. 208 shutdowns per year represents 4 shutdowns per week for 52 weeks in the year, also from Reference [8].

It is seen in Table 2 that the estimated current percentage increase in absorber volume of 0.045%, is a small fraction of that plotted in Figure 2, ranging from 0.4 to 1.7%.

In Table 2, the predicted linear strain for the absorber element is 0.356%, which assumes isotropic expansion of the absorber material. Although the exact composition of the Control Rod nickel-tin Sheath was not researched, even with irradiation, it is expected that cracking of the Sheath would not be possible at such a low level of strain because of the high ductility of the nickel-based alloys.

4.2.2 Assessment of the Potential for Control Rod – Fuel Bundle Interference due to Absorber Swelling

From Table 2, the estimated current transverse elongation of the Control Rod cross-section is 0.008 inches over a nominal length of 2.25 in. Referring to Figure 2, the 0.008 inch elongation of the Control Rod cross-section means that the 0.1225 in gap with the Fuel Bundle would be reduced by 0.004 inches (only 3%) over 60 years of operation. Therefore, interference of the Control Rod with the Fuel Bundle, due to swelling, is not a concern for this assessment, or for the foreseeable future.

4.3 Assessment of the Potential for Control Rod – Fuel Bundle Interference due to Control Rod Bowing

Bowing deformation of the Control Rod could originate from:

1. In-service temperature differences in the Rod that cause it to bow during storage above the core because of differential thermal expansion. There is no evidence of any significant side-to-side operating temperature differences when the Control Rod is stored under minimal fast neutron flux, so that Control Rod – Fuel Bundle interference due to Control Rod thermal bowing can be ruled out.

2. Side-to-side differences in fast neutron flux on the Control Rod, leading to bowing during Control Rod storage because of differential irradiation-induced growth. This source of bowing can be ruled out since the Control Rod is stored under minimal fast neutron flux, so that Control Rod – Fuel Bundle interference due to differential irradiation of the Control Rod can be ruled out.

3. Shape distortion of the Control Rod due to the irradiation-induced relaxation of residual stresses from the manufacturing of the Control Rod. Technically, this type of deformation cannot be ruled out without a detailed analysis of the residual stresses in the Control Rod from manufacturing (which was not feasible for this assessment). However, it is known from the Control Rod drop time measurements that stress relaxation has not yet distorted the Control Rods sufficiently to influence the drop time. It is very unlikely that there will ever be sufficient distortion of the Control Rods to result in Control Rod – Fuel Bundle interference due to Control Rod shape distortion.

5. Conclusions

1. In reality, the absorbers in the MNR Control Rod do have a tendency to swell with irradiation. Reference [2] is technically inaccurate in saying that the absorbers have no tendency to swell. The inaccuracy is inconsequential since the swelling rate was predicted to be acceptably small.

2. A brief fitness-for-service assessment of MNR Control Rod degradation has found that Control Rod bowing, due to differential thermal expansion and irradiation, can be ruled out and that the rate of absorber swelling was predicted to be extremely low.

3. Therefore, Control Rod-Fuel Bundle interference, leading to difficulties with the Control Rod insertion function, would not be possible over the next 20 years of operation, which helps to support the case for operation of the MNR to 2044.

6. References

4. E-mail Message from C.J. Heysel, McMaster Nuclear Operations and Facilities to P.J.Sedran, “Swelling of the absorber material in the Control Rod”, Feb 29th, 2024.

5. PWR CONTROL ROD DEGRADATION AS OBSERVED IN POST-IRRADIATION EXAMINATIONS IN STUDSVIK, XA0053628 T. Jonsson, Studsvik AB, Nykoping, T. Anderson, L. Bjornkvist, Vattenfall AB, Ringhals, Varobacka, Sweden.

6. FRAMATOME CONTROL ROD ABSORBER MATERIALS: XA6O53641 EXPERIENCE AND DEVELOPMENT, M. Monchanin, Franatome Nuclear Fuel, Lyon, France, X. Thtoault, EDF Septen, Villeurbanne, France,

7. E-mail Message from Cappon, Derek, McMaster Nuclear Operations and Facilities to P.J.Sedran, “Reactivity Control Mechanism details for MNR”, December 15, 2023.

8. E-mail Message from C.J. Heysel, McMaster Nuclear Operations and Facilities to P.J.Sedran, “Swelling of the absorber material in the Control Rod”, 03/01/2024.