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OPERATIONAL MONITORING OF SMALL MODULAR REACTOR FACILITIES THE 4TH INTERNATIONAL TOPICAL MEETING ON SMALL REACTORS (ITMSR-4)

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ABSTRACT

Small Modular Reactor (SMR) facilities are expected to be operated with minimal expert staffing, which suggests the need for continuous monitoring of equipment and containment largely free of human supervision. To this end, CNL is investigating the following:

- Inspection issues that might impact the (regulatory) licensing of SMR facilities in Canada.
- Methods of unattended monitoring of process equipment of an operating SMR.
- Unattended monitoring to assure the structural integrity of SMR containment, particularly concrete.

Review and survey investigations have identified potential mitigating factors in SMR operating licenses that may be realized due to design features. Present regulations for Canadian reactors are influenced by CSA standards, with N285.4 playing a prominent role. Chief among the mitigating factors for SMR application are the design differences between these small reactors and CANDU power stations, such as: low power output, passive safety systems, fuel load, and potential remote locations. Relief from the relatively stringent requirements that are necessary for large power reactors may be realized by considering IAEA recommendations for a graded approach toward the safety of research reactors, applied to SMR, which could be reflected in longer service intervals, factory servicing of modules, remote monitoring, and nested barriers between the primary heat transport system pressure-boundary and the environment.

Methods of monitoring equipment without the need for numerous operating staff have been identified, but so have challenges due to the novel and unique nature of SMR designs. SMR monitoring challenges are presented by high coolant temperatures, corrosive coolant media, and fast neutron flux, which may dictate the need for special instrumentation. Integral designs can impose spatial constraints, rendering sensor selection difficult, and unconventional process systems might not have well established performance histories. Technical uncertainties have been identified: reliability and accuracy of new sensors is not known, new dedicate (e.g., optical) sensors will be

required, integral design sensor replacement strategies must be developed, on-line monitoring must cope with signal degradation, especially if regulatory acceptance is to be attained. These uncertainties provide the challenges for R&D programs to address.

SMRs with conventional containment structures surrounding the reactor are expected to share the concerns of large-reactor power stations. CANDU industry experience has made note of the following: reinforcement corrosion, cracking and its growth, stress-relaxation of post-tensioned tendons and related dimensional changes, spent-fuel bay temperature excursions, and age-induced changes in compressive strength, especially those brought on by freeze-thaw cycling, which will be an environmental condition for the majority of Canadian-sited SMRs. Structural integrity verification and time-monitoring of containment (concrete) can be accomplished by adapting existing nondestructive monitoring technologies, using embedded sensors. The extent of the capabilities of these technologies and gaps in SMR requirements are not fully known, but are the subject of R&D work presently being conducted.

Survey work addressing the above concerns have been ongoing at CNL since 2013/14.

Experimental work at CNL has concentrated on passive containment concrete monitoring. The bulk of effort presently underway investigates the detection of freeze-thaw induced deterioration of containment concrete strength. Two initial experiments have been underway since 2014 November and 2015 March. They involve, respectively:

- Monitoring of in-ground thermistor (temperature) sensors, to determine their practicality and longevity (Figure 1), and
- Recording the ultrasonic (pulse) transit-time through a concrete block that is subject to climatic cycling, using embedded sensors, to assess the functionality, longevity, and sensitivity of concrete-embedded ultrasonic transducers. (Figure 1)

The thermistor tests make use of three sensors placed at different levels in the ground. Thermistors are solid-state temperature-following elements, having electrical resistance that depends on temperature. They display generally higher sensitivity to small temperature change than the more-commonly-used RTD or thermocouple sensors, and can be configured for a negative temperature coefficient[1], which is preferred for this work. In this test, three thermistors were placed in the ground at depths of 300 mm, 150 mm and 0 mm. Readings of resistance have been taken with a typical time interval that has increased from once per week to once every two weeks. The expectation upon installation in the ground was that a temperature profile reflecting the yearly average temperature variations of the Ottawa valley would be seen. An anomalous but nonetheless useful result was in fact seen due to a leaking steam-condensate pipe in the ground nearby; the ground where the thermistors reside has never frozen since their installation. A plot tracking the chronological temperature readings of the in-ground thermistors is shown in Figure 2.

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1 Negative Temperature Coefficient (NTC) => resistance decreases as temperature increases.

Ultrasonic pulse transit-time monitoring has been performed on the block shown in Figure 1 since 2015 March. A "pitch" and a "catch" transducer were bonded permanently into recesses cast into the block-ends, using small-aggregate concrete as a mortar. This was in itself a test of sorts, since the embedment of ultrasonic transducers in concrete is rare. Results have shown the embedment to have been successful with minimal effort. Because the transducers are not completely embedded, tension rods have been applied to prevent the bond being broken by an outside shearing force. Placed out-of-doors, the transit time for acoustic energy pulses can be monitored continuously or periodically by attaching a pulser-receiver or dedicated UPV instrument, with an oscilloscope for waveform display. Waveforms and screen-displays are easily acquired through the Universal Serial Bus (USB) interface of a digital oscilloscope. First order changes in the material properties of the concrete are expected to be seen in the time taken for acoustic energy to traverse the length of the block, since changes in material properties are known to correlate with pulse speed. Multiple ultrasonic (pitch-catch) waveforms from different times of acquisition are shown in Figure 3. (Time taken to traverse the length of the block is given by the interval between the small signal near t=0 and the commencement of the RF oscillations. Apparent differences in this time interval from one date to the next can be attributed to differences in ambient temperature at the times of acquisition.)

Containment monitoring work is continuing. Further expansion of the experimental program will involve:

- Freeze-thaw tests with high (yearly) cycling frequency.
- Incorporation of embedded-sensor temperature monitoring into the high-frequency temperature cycling tests.
- Adaptation of optical sensors for structural-dimensional monitoring.

The objective is the demonstration of methods whereby the ageing of concrete containment in SMR stations can be monitored using passive-automated methods, which will show ageing to be progressing as expected in the design-basis or provide early warning of abnormal deterioration. This is considered to be a feasible objective.

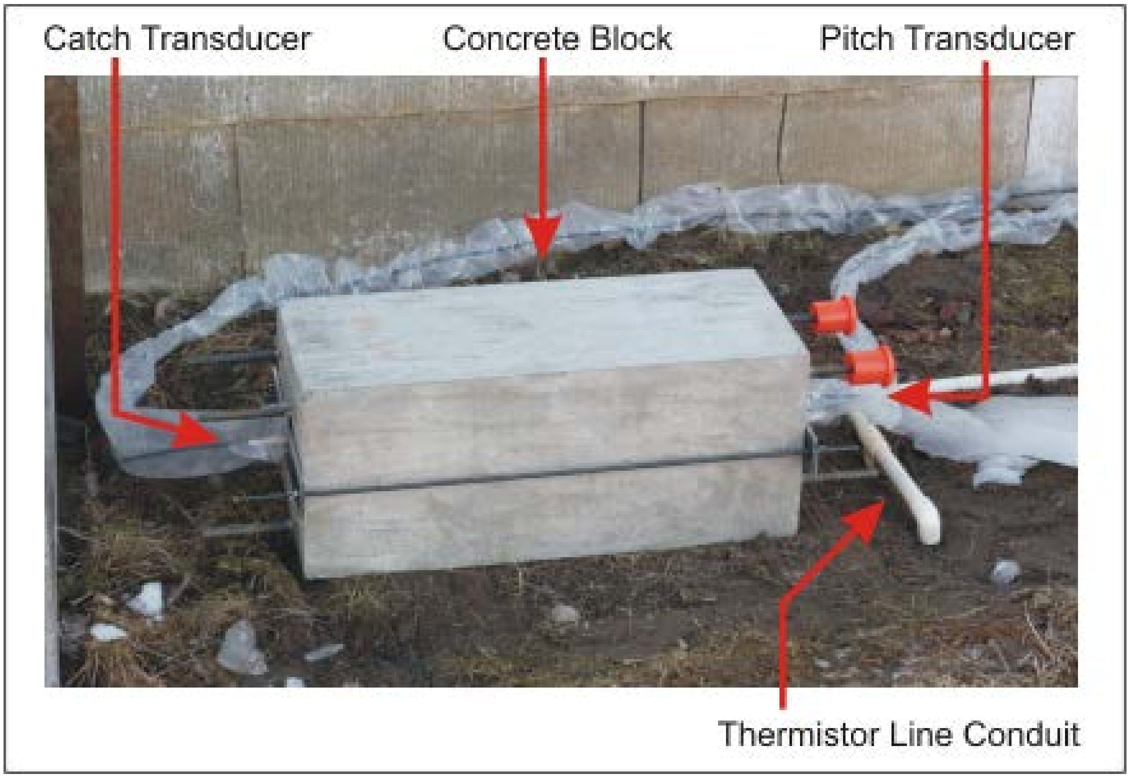

Figure 1: Initial Ultrasonic Pulse Velocity Experiment

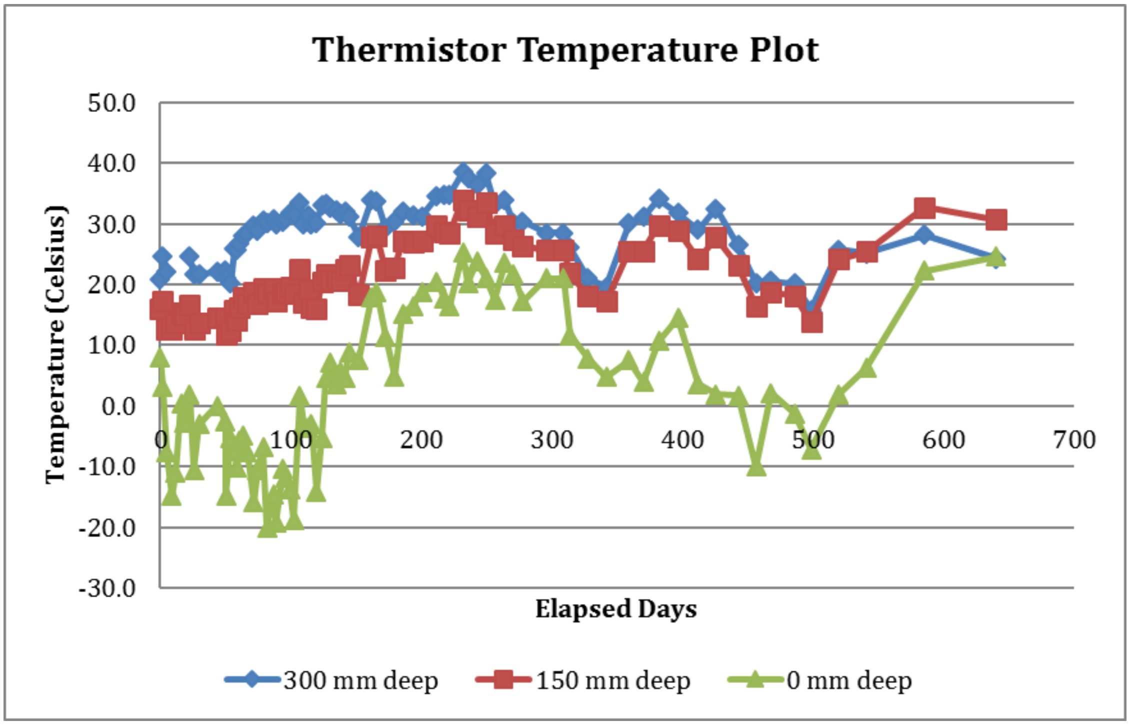

Figure 2: Thermistor Temperature Tracking

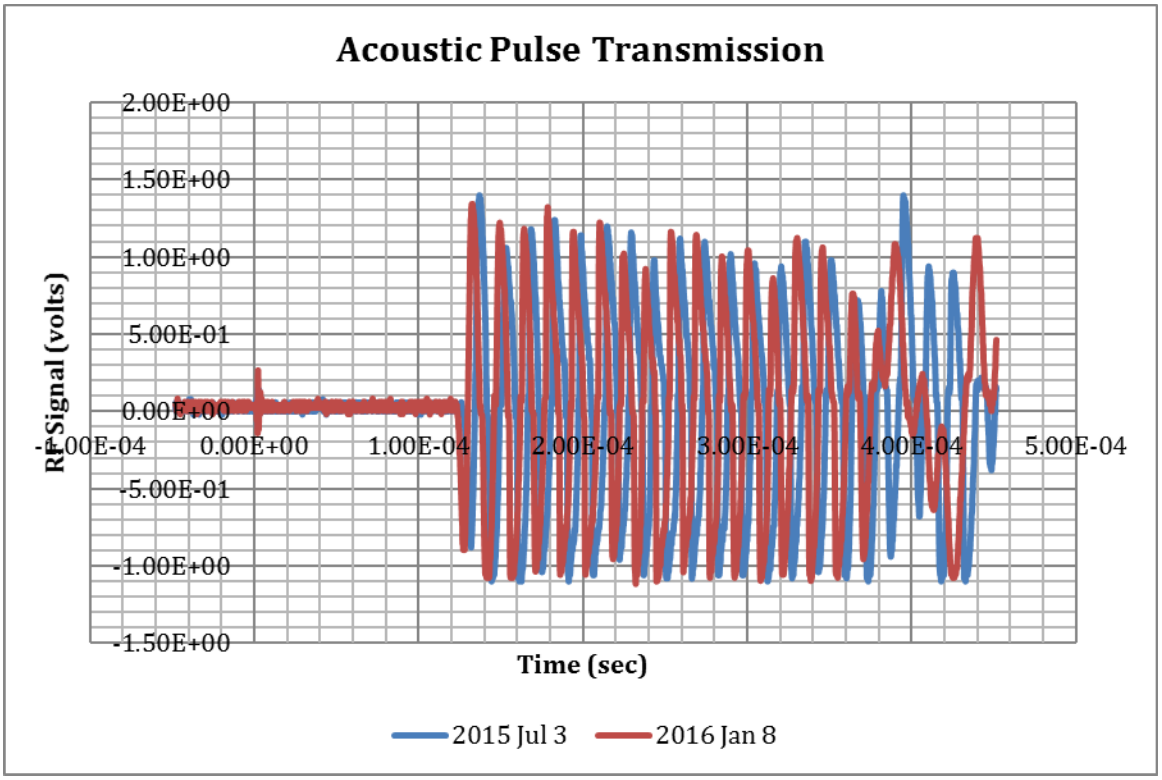

Figure 3: Ultrasonic Pulse Monitoring