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The New Emergency Core Cooling (NECC) System for the National Research Universal (NRU) Reactor

by

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ABSTRACT

The New Emergency Core Cooling (NECC) system is the penultimate of seven major safety upgrades being implemented at the National Research Universal (NRU) Reactor in Chalk River. The NECC upgrade was designed to improve the original systems for core cooling in the event of an unisolable failure within the primary cooling circuit. The NECC upgrade ensures that water is automatically made available to the emergency cooling circuit pumps in the event of a break. Reactor core cooling is achieved from the discharge of these pumps which distribute emergency coolant to the individual fuel rods. Heated water from the vessel returns to the heat exchangers within the emergency cooling circuits for heat removal to the secondary coolant. The NECC upgrade significantly improves protection for a wide range of Loss Of Coolant Accidents (LOCAs) through the use of design features such as component redundancy, automatic initiation and hazard qualification. The introduction of the NECC upgrade combined with previous improvements in liquid confinement capability provide a closed loop system that ensures stable long term reactor core cooling. CATHENA (Canadian Algorithm for THErmalhydraulic Network Analysis) analysis was performed to assess the NECC upgrade and to validate the design for credible leak scenarios.

INTRODUCTION

The NRU Reactor is a 135 MW thermal research facility owned and operated by Atomic Energy of Canada Limited (AECL) and is located at the Chalk River Laboratories in Chalk River, Ontario. In the early 1990's, a systematic review and assessment of the NRU Reactor was undertaken to determine the physical condition of NRU systems and to identify the need for safety improvements. The assessment concluded that the overall condition of NRU was good and that continued operation posed no undue risk to the health and safety of the public or the environment. The assessment also identified seven (7) major safety upgrades to enhance the level of safety consistent with modern safety standards. The New Emergency Core Cooling (NECC) upgrade is one of the seven major safety upgrades. This paper outlines the design basis, the system description, hazards qualification, the commissioning and the system operation. In addition, a discussion of the CATHENA analysis used to validate the design is provided.

NECC DESIGN BASIS

Over the 42 years of NRU operation, there has never been a LOCA requiring the use of the existing emergency light water injection system. Several heavy water leak incidents have occurred over the years including two major pump seal failures and a partial circumferential break of a 1¼" heavy water line connected to the bottom header. The leak rate following the failure of this line was estimated at 10 Igpm.

Based on the extensive operating history and the failure assessment of the NRU Primary Coolant System piping, a list of LOCA initiating events was developed. These included failures up to and including complete severance of smaller diameter (≤3") unisolable piping connected to the main heavy water circuits, or, from a break in any of the larger diameter piping up to a maximum leak rate of 500 Igpm. Therefore, a design basis leak rate of 500 Igpm bounds all LOCA scenarios up to and including complete guillotine failure of the smaller unisolable branch piping connected to the heavy water system.

The design does not cater to the guillotine failure of the largest piping connected to the bottom header. The decision not to accommodate the larger diameter piping failure was based on the following:

- the results of a comprehensive heavy water system inspection program consisting of visual inspection, ultrasonic testing, radiographic testing, eddy current inspection, liquid penetrant testing and destructive examination,
- a seismic analysis of the heavy water system,
- the benign operating conditions of the system,
- the large safety margins imposed during original construction,
- stringent chemistry control and
- the lack of any credible failure mechanism.

These factors confirmed that a sudden guillotine failure of large bore piping within the heavy water system is a beyond-design basis event and that any failure, if it were to occur, would be limited to a leak-before-break scenario. In this case, operator action can be credited as an effective line of protection.

SYSTEM DESCRIPTION

The primary coolant system operates at 50 degrees C and 110 psi and consists of eight parallel circuits, each with its own primary coolant pump and heat exchanger. Four of the eight pumps are equipped with two-speed AC motors and standby DC motors. Two of these four pumps are supplied heavy water from connections to the bottom header of the reactor. These two circuits are referred to as emergency cooling circuits 4 and 5.

The existing Emergency Process Water Injection is a manually operated, open loop system that has the potential to flood the reactor building resulting in water escaping from the building and threatening the operation of the primary cooling circuit pumps. Fundamental requirements of the NECC design were to reduce the dependence on the operator for diagnosis of a LOCA event and initiation of the emergency core cooling system, to retain and recycle emergency cooling water to ensure long term cooling and to eliminate the potential for flooding and the spread of contamination. Thus, the NECC upgrade is a closed loop, hazards qualified, auto-initiating system that maintains stable long-term core cooling provided secondary cooling water supply to the emergency cooling circuits remains available. Long-term core cooling is achieved by collecting water from the leak and returning it via the NECC sump pumps to the suction side of the emergency cooling circuit pumps (P-104 and P-105) which discharge emergency coolant to the reactor core. Heated water from the vessel returns to heat exchangers 4 and 5 in the emergency cooling circuits for heat removal to the secondary coolant. The Qualified Emergency Water Supply (QEWS) upgrade provides a closed loop, seismically qualified heat sink to the secondary side of the heat exchangers in the emergency cooling circuits in the event that normal process water cooling, emergency process water cooling and fire water cooling supplies to the heat exchangers are lost.

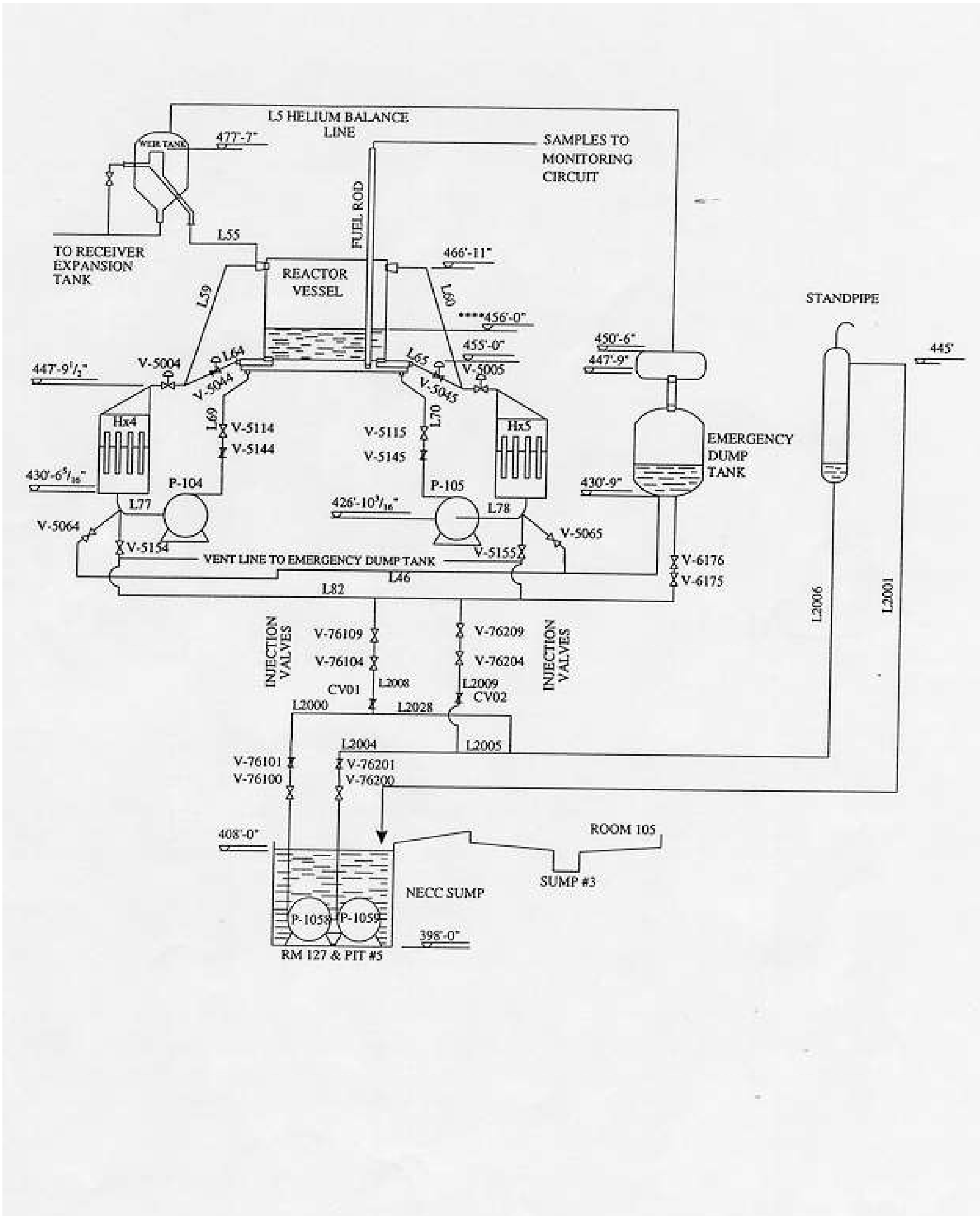

Figure 1 - New Emergency Core Cooling (NECC) Simplified Flowsheet

The NECC upgrade consists of a reservoir/sump, new sump pumps, supply and drain lines, and level instrumentation for the sump, reactor vessel and emergency dump tank. A common bypass line and standpipe divert part of the NECC pump flow back to the sump when catering for leaks less than the design basis. The standpipe passively controls the net positive suction head to the suction side of the emergency cooling pumps (P-104 and P-105). Two identical pump trains consisting of a pump and injection valves, recirculate water from the sump back to the suction side of emergency cooling pumps. When operating in the redundant mode, each circuit of the NECC system is capable of supplying up to 800 Igpm of water for emergency core cooling. In a non-redundant mode, NECC is capable of supplying up to 1600 Igpm. A simplified flowsheet is shown in Figure 1.

The NECC system, together with the Liquid Confinement system, effectively provides the closed loop emergency cooling system. The Liquid Confinement System was designed and installed as part of the Liquid Confinement Vented Confinement (LCVC) system safety upgrade. The liquid confinement boundary ensures that all heavy water leakage from the primary cooling system is contained within the LCVC boundary and is directed to the NECC sump in the event of a LOCA .

Figure 2 shows the confinement boundary and drainage flow paths to the NECC sump. The drainage system is designed for rooms containing primary cooling system piping and consists of floor drains, holes in existing concrete floors, steel or concrete curbs to contain liquids, sloped floors and drain pipes. Good housekeeping practice is enforced in all confinement areas.

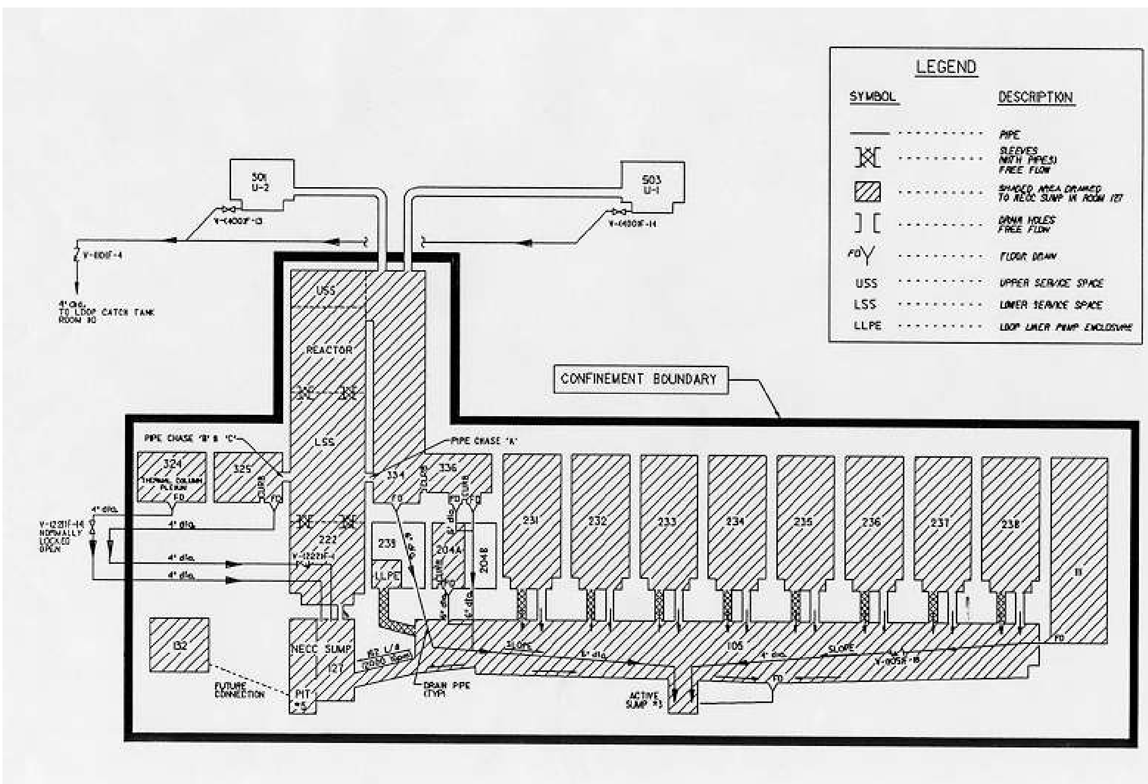

Figure 2 - NECC and Liquid Confinement Drainage Upgrades Flowsheet

System Instrumentation and Control

The instrumentation and control system for the NECC system is seismically qualified and designed in accordance with the guidelines of the applicable CSA Nuclear standards. The main control panel is located in the Qualified Emergency Response Centre (QUERC), a hazards qualified location within the reactor building used to control and monitor each of NRU Upgrade Safety Systems. A similar auxiliary panel is located in the NRU Control Room which receives buffered signals to ensure that the control logic in the hazards qualified QUERC is protected at all times.

The instrumentation and control logic performs the following functions:

- Monitors water levels in the reactor vessel, the emergency dump tank and the NECC sump using separate triplicated instrumentation.
- "Poises" the system by starting the NECC pump that is selected to AUTO on indication of a high sump level.
- Initiates automatic injection when the two out of three logic is satisfied on all three initiating parameters (low reactor vessel level, low emergency dump tank level and high NECC sump level).
- Provides control for all valves essential to NECC operation.
- Provides for manual NECC initiation from the QUERC and the Control Room.
- Provides for manual operation of Process Water Injection valves for make-up purposes.
- Provides monitoring and alarm annunciation of abnormal (fault) conditions.
- Monitors and displays key parameters including reactor, dump tank and sump levels, valve status, standpipe flow and injection valve leakage.
- Prevents individual push-button operation of the injection valves until one or more of the parameters has returned to its normal range and the initiation logic has been "reset".

Auto-initiation of NECC on a two out of three logic on three key parameters provides an inherent reliability in order to minimize the probability of spurious injection and the serious economic penalties that would result.

OPERATION

There are three modes of operation for the NECC system. During normal reactor operation, the system is in the "standby" mode. In this mode, the NECC sump is filled with an inventory of about 12,800 Igal of light water, with one NECC pump selected to "AUTO" and the other on "STANDBY". The auto injection valves are closed and the manual isolation valves in the emergency cooling circuits and in the dual NECC injection trains are open.

In the event of an unisolable heavy water leak on critical piping connected to the bottom header, the sequence of events is as follows: the reactor vessel level drops, the reactor trips on an existing low vessel level trip, and all of the primary cooling system pumps shutdown except for the emergency cooling pumps (P-104 and P-105) which slow to half speed. As the leak progresses, the level in the NECC sump increases. When the level in the sump increases by 8" above normal (1000 gal), the NECC pump selected to "AUTO" will start. Water discharged from the NECC pump recirculates through the standpipe and returns to the NECC sump. The auto injection valves remain closed. This mode of operation of the system is referred to as "poised".

The heavy water level in the vessel will eventually fall below 1 foot in the vessel which satisfies the second initiation parameter for NECC. If the level in the emergency dump tank is below 9 feet, the third NECC initiation parameter is satisfied, and automatic injection is initiated. An equilibrium level in the vessel will be established and water in excess of the leak rate flows over the standpipe and returns to the NECC sump. This mode of operation is referred to as the "injection" mode.

Operating procedures are being revised to reflect the new installation.

HAZARDS QUALIFICATION

The existing emergency cooling systems are not hazards qualified. As modern standards for safety system design advocate protection for design basis events including tornado, fire, flooding, and in particular, seismic events, the NECC design considers these hazards.

The approach taken for NRU with respect to seismic activity was to qualify existing structures to the Assessment Basis Earthquake (ABE) level (frequency $10^{-2}/_{y}$) and to qualify new structures and equipment to the more severe Design Basis Earthquake (DBE) level (frequency $10^{-3}/_{y}$). This philosophy was used to qualify - to the DBE level - those components required to provide the four fundamental safety functions, ie: shutdown, cool, contain and monitor. Where required, NRU Upgrades related to these functions were, therefore, qualified to the DBE level and the environment around these systems, such as support structures, were qualified to the ABE level. NECC piping and equipment, including portions of the existing heavy water system will be qualified to the DBE level. In addition, a reactor seismic trip has also been incorporated into the Second Trip System upgrade with a set-point 15% below the threshold of the ABE level.

Seismic qualification using this philosophy was considered to be the most practical approach to allow the NRU Upgrades Safety Systems to meet modern day seismic safety standards in accordance with the guidelines of the applicable CSA Nuclear standards for seismic qualification.

COMMISSIONING AND INSTALLATION

The commissioning of the NECC system will be completed in accordance with the NECC commissioning plan. Detailed commissioning procedures will be used to demonstrate that the system meets its design specifications and is operable and reliable by verifying the functionality of individual components, the control logic and the overall performance of the new system. Specifically, commissioning procedures will be written for the testing of instrumentation, control circuitry, initiation logic, alarms, valve modifications NECC pump operation and pressure boundary integrity. A simulated injection test will be conducted to determine an accurate injection pressure for comparison with CATHENA predictions. Commissioning procedure preparation is in progress with commissioning expected to begin in October 2000.

Due to the intrusive nature of these modifications on safety-critical components, a separate Installation Plan is being prepared to provide a means to accurately track the system configuration before and after each commissioning test. Hold points will be clearly identified in the procedures where the AECL Safety Review Committee and regulatory approvals are required.

CATHENA VALIDATION

The CATHENA computer code was used to analyze the hydraulic characteristics of the NRU primary cooling system, the emergency dump tank and the NECC circuits. The code was used to predict the operation of the combined primary cooling and NECC circuits under various equipment failure conditions using the design basis bounding leak rate scenario. In addition, CATHENA simulations were used to show that NECC will provide an automatic back-up to operator action for very small unisolable leaks without over-pressurizing any part of the low pressure heavy water system. The results of the simulations were evaluated against the pre-determined acceptance criteria of continuous fuel rod flow. The equipment failure conditions that were modeled include:

1. failure of one of the two redundant NECC injection trains,
2. failure of one of the two emergency cooling circuit pumps (P-104 or P-105) to run,
3. loss of power which results in emergency cooling circuit pumps to operate on their standby DC motors,
4. NECC injection with water in the emergency dump tank as a result of a controlled dump in the small leak scenario, and
5. loss of power to the emergency cooling circuit pumps and the NECC pumps following a LOCA.

The CATHENA simulations demonstrate adequate long-term core cooling by the NECC system is maintained under the postulated LOCA scenarios. The results also show that NECC is capable of providing an automatic back-up to operator action in the small leak rate scenario without over-pressurizing any part of the heavy water system.

CONCLUSIONS

The NECC upgrade provides an uninterrupted, closed loop, long-term core cooling system that adds an additional layer of protection for the NRU Reactor in the event of a LOCA. The upgrade significantly improves the LOCA protection using key features such as component redundancy, hazards qualification and automatic initiation. The automatic initiation feature eliminates the requirement for human intervention in the short term, under the high stress conditions, to ensure successful operation of the emergency cooling system. The completion of the NECC upgrade will provide an improvement to safety without adversely affecting existing systems.