SAFETY UPGRADES TO THE NRU RESEARCH REACTOR

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ABSTRACT

The NRU (National Research Universal) Reactor is a 135 MW thermal research facility located at Chalk River Laboratories, and is owned and operated by Atomic Energy of Canada Limited. One of the largest and most versatile research reactors in the world, it serves as the R&D workhorse for Canada's CANDU business while at the same time filling the role as one of the world's major producers of medical radioisotopes.

AECL plans to extend operation of the NRU reactor to approximately the year 2005 when a new replacement, the Irradiation Research Facility (IRF) will be available. To achieve this, AECL has undertaken a program of safety reassessment and upgrades to enhance the level of safety consistent with modern requirements. An engineering assessment/inspection of critical systems, equipment and components was completed and seven major safety upgrades are being designed and installed. These upgrades will significantly reduce the reactor's vulnerability to common mode failures and external hazards, with particular emphasis on seismic protection. The scheduled completion date for the project is 1999 December at a cost approximately twice the annual operating cost. All work on the NRU upgrade project is planned and integrated into the regular operating cycles of the reactor; no major outages are anticipated. This paper describes the safety upgrades and discusses the technical and managerial challenges involved in extending the operating life of the NRU reactor.

INTRODUCTION

NRU is a multi-purpose research reactor, heavy water moderated and cooled with a core consisting of a reactor vessel 3.7 m high and 3.5 m in diameter made up of 227 vertical lattice sites arranged in a hexagonal array. Low enriched uranium fuel and control/safety rods occupy approximately 50% of the core; the remaining sites are available for experiments and isotope production. Eight horizontal beam tube facilities support a variety of neutron scattering experiments and two high-pressure/high-temperature loops are used extensively for:

- proof testing prototype fuels and materials
- power ramping tests on fuels
- accident transient tests (severe fuel damage)
- thermal hydraulics and corrosion studies

A dedicated Blowdown Test Facility (BTF) is also available to support AECL's program on fuel behaviour and fission product release under accident conditions.

The NRU reactor was first started up in 1957 November, and despite many changes to its configuration and programs, NRU has compiled an impressive record of achievements:

- first reactor to successfully change fuel while operating at full power.
- converted from natural uranium to 93% U-235 enriched fuel in 1964.
- replaced the aluminum reactor vessel in 1974.

- conducted severe fuel damage Loss of Coolant Accident (LOCA) tests on full length production Pressurized Water Reactor (PWR) fuel in the early 1980's.
- converted to low enriched uranium (20% U-235) in 1992.

Since the NRX reactor was taken out-of-service in 1992, the demands placed on NRU operation have increased significantly. Radioisotope customers demand an uninterrupted production of short lived isotopes such as Molybdenum-99 while fuel and materials irradiation programs require frequent shutdowns for experimental changes. Despite these conflicting demands on its operating schedule, NRU continues to perform with unfailing consistency, achieving an annual capacity factor of approximately 80%.

Over the last several years, significant efforts have been invested in formalizing the conduct of operations (management processes) within NRU, consistent with Canadian nuclear standard CAN3-N286.5 and with guidance from the International Atomic Energy Agency (IAEA) and Institute of Nuclear Power Operations (INPO) documentation. Improvements have been introduced in the areas of operator training, unplanned event investigation, change control and equipment aging management programs. All of these were factored into the decision to extend the operating life of the NRU reactor, and indeed are contributing to the successful implementation of the upgrades project.

ENGINEERING AND SAFETY ASSESSMENT

A systematic review and assessment of the NRU reactor was completed in 1991 as part of AECL's business planning process. This study consisted of an engineering assessment supported by limited scope safety analyses with the overall objective of determining the physical condition of NRU systems and identifying any required safety upgrades. All systems and components critical to safety were examined. Particular emphasis was placed on aging, obsolescence, and seismic vulnerability.

A seismic philosophy was developed for NRU, that attempts to have NRU meet modern day seismic safety standards as much as practical. A Design Basis Earthquake (DBE) with a return frequency of one in a thousand years, and a less severe Assessment Basis Earthquake (ABE) with a return frequency of one in a hundred years were defined for the Chalk River site. The approach taken was to qualify those components required to ensure insertion of reactor shutdown devices on a reactor trip and to maintain the reactor core cooling after shutdown to the DBE. New upgrades related to these functions must also be qualified to the DBE. The environment around these systems, including the support structures must, at a minimum, be qualified to the ABE. The use of this philosophy has been extremely useful in identifying specific areas of vulnerability and in the subsequent design of the safety upgrades.

This initial assessment concluded that the overall condition of NRU was good and that continued operation posed no undue risk to the public or the environment. In addition, 7 major upgrades were identified to enhance the ability of the reactor to meet modern safety standards. Approval to proceed was given by AECL executive management in 1992.

SAFETY UPGRADES

Licensing Basis

The reactor is operated to a Facility Authorization document that defines the Limiting Conditions for Safe Operation in accordance with the Chalk River site licence. Up-front agreement was reached with the regulator, the Atomic Energy Control Board, that each upgrade would be approved and licensed as a modification under the change control provisions of the Facility Authorization provided the following criteria could be demonstrated:

- it provides a significant net improvement in safety,

- it has no adverse effects on the existing configuration of NRU and
- it meets its design and performance specifications.

In addition, a number of practical considerations were factored into the designs to minimize interference and crosslinks with existing systems and to ensure that the upgrades could be completed within a reasonable time frame and without a major reactor outage.

QUALIFIED EMERGENCY RESPONSE CENTRE (QUERC)

The QUERC upgrade is essential to the other upgrades. It provides a hazard-qualified location within the reactor building for the instrumentation and control cabinets of the other upgrades; it also serves as an alternate location to initiate and monitor the safe shutdown of the reactor, should the main control room become uninhabitable in an emergency. The new facility was completed in 1996.

The QUERC upgrade permits the grouping and separation of NRU safety functions. The existing Group 1 safety systems are located in the main control room and the Group 2 systems (comprising the upgrades) are controlled and monitored from the QUERC location. Each group is independently capable of shutting down and cooling the reactor and confining the reactor fission product inventory. This arrangement ensures that common-cause events and functional inter-connections do not impair the overall capability of the engineered safeguards to perform essential safety functions.

Second Trip System (STS)

The original NRU trip and shutdown system was designed with many of the features that are standard today - high reliability, high redundancy and fully testable. The shutdown mechanisms, absorbers supported by electromagnets, have proven to be highly reliable. In 40 years of operating experience involving > 21,000 individual shutdown rod releases, no failures or near misses have occurred to suggest any design or operational vulnerability to common cause events. Nevertheless, the safety analyses did identify concerns in the areas of physical separation and vulnerability to external hazards.

Modification of the existing system was considered highly impractical and the decision was made to add a new independent trip system but retain the proven shutdown rod mechanisms. The STS is hazards qualified, is independent of the original trip system and is fully independent of the control system. Equipment cabinets are located in the QUERC with buffered slave cabinets in the existing control room. Four critical trip parameters are monitored (Table 1) using general coincidence logic and an emergency manual trip is provided.

Table 1 STS Trip Parameters and Set-Points

STS TRIP PARAMETER	TRIP SET-POINT
excess linear neutron level	100%
excess log rate of increase in neutron flux	5% per second
high building vibration (seismic trip)	0.06 g in all three axes
loss of Class 4 electrical power	70% of normal RMS voltage - 380 ms delay
manual trip - main Control Room	N/A
manual trip - QUERC	N/A

In conjunction with the STS upgrade, several well defined and contained engineering changes to existing systems and equipment were required. The final installation was successfully commissioned and placed in service in 1997 July.

Liquid Confinement Vented Confinement (LCVC)

The LCVC is the only upgrade that comprises improvements to an existing Group 1 system rather than an additional safety system. The NRU reactor was designed with a well defined confinement boundary enclosing the reactor structure, the primary circuit and the active drainage room. In the event of an accident, these areas are exhausted to a state-of-the-art emergency filter building where iodines and particulates are removed. The following significant improvements have been made:

- liquid drainage has been improved to cope with larger leak rates,
- a new central drainage sump has been added,
- over-pressure protection for the structure in the event of piping failure in the high pressure experimental loops,
- fully automatic "box-up" controls,
- improved boundary monitoring and access controls, and
- structural building modifications.

A seismic assessment completed on the confinement boundary confirmed that the structure has adequate strength to resist seismic loads from an ABE; in addition, the drainage provisions have been qualified to the DBE primarily because they support the New Emergency Core Cooling (NECC) system. Work on the LCVC is nearing completion and commissioning is planned for 1998 January. The major benefit anticipated from the LCVC is improved accident management capability, indirectly leading to a reduction of public doses in an accident scenario.

New Emergency Core Cooling (NECC)

The existing reactor emergency cooling system is a manually actuated light water injection system; it is powered by existing power supplies and is not hazards qualified. A new system, the NECC, has been designed to provide long-term reactor core cooling in the event of a loss of coolant accident. It incorporates the following key features:

- a closed loop system that caters to leaks of up to 2000 IGPM,
- fully automatic actuation and
- seismically qualified to the DBE.

This system utilizes new qualified power supplies and the improved drainage and leak collection provisions of the LCVC. Two identical piping circuits, each incorporating a pump and injection valve, recirculate cooling water from the NECC sump/reservoir back into the primary coolant circuits. All of the existing primary circuit piping has been inspected and seismically qualified to the DBE. The qualified completion date for this upgrade is 1999 December.

Main Pump Flood Protection (MPFP)

This modification is intended to reduce the vulnerability of the reactor's primary coolant circuit pumps to flooding in the event of a major failure of the process water system piping. Detailed design is currently in progress with a final installation date of 1999 March.

Qualified Emergency Water Supply (QEWS)

This final upgrade will provide a seismically qualified heat sink for the secondary side of the main heat exchangers. The conceptual design is in place and the expected completion date is 1999 November.

REACTOR SAFETY EVALUATION

Coincident with the upgrades, a revised safety analysis of the reactor is in progress, using recommendations given in IAEA Safety Series 35-G-1 [1]. Modern standards and up-to-date analytical tools are being used to assess the upgraded NRU reactor.

Limited scope studies of initiating events using both probabilistic and deterministic techniques are used as the framework for the safety analysis plan. A comprehensive set of initiating events were identified based on both the NRU design and external sources and have been arranged into logical groupings. Event sequences are being prepared for each initiating event and based on best available information, bounding sequences for each event group will be identified for detailed analysis. This determination can be made with a high degree of confidence because of the extensive operating experience with the NRU design.

Fault tree and event tree analysis will then be used to quantify the bounding event sequences and deterministic analysis will be used to assess the accident consequences and the consequence of mitigating system failure in the event sequences. Extensive use has been made of the CATHENA thermal hydraulics code in modelling the NRU cooling systems and an in-house point kinetics transient code is being used for analysing reactivity transients.

It is proposed to issue the Safety Report for the upgraded NRU reactor in two stages. A revised Safety Report will be issued in 1998 consolidating all current information on NRU including the new safety upgrades. The Final Safety Report will be issued in 1999 after all of the safety analysis has been completed.

In addition to the safety analysis program described above, a number of specific assurances were provided to the regulator in the form of separate safety reports. These included:

- a review of the vulnerability of the reactor to external hazards including seismic,
- assurances that up-to-date surveillance testing and maintenance programs are in place for the existing shutdown system and that component/equipment aging is effectively managed
- justification for the decision not to install a second diverse shutdown system.

STATUS OF UPGRADES

The initial two upgrades, the QUERC and the STS, have been installed, commissioned and put in service; the LCVC is nearing completion and will be in service early in 1998. Table 2 provides an overview of the project costs and the completion dates. Project support costs include project management costs and senior engineering and management costs from the various functional groups-operations, maintenance, design, procurement, safety and licensing and quality assurance. The $40.7 M overall cost incorporates a $6.0 M allowance for risk and contingency.

Table 2 NRU Upgrades Project Status and Costs (as of 1997 November)

	TARGET DATE	COMPLETION %	COST ($M)
QUERC	1996 Dec	100	1.3
STS	1997 July	100	3.9
LCVC	1998 May	90	4.8
NECC	1999 December	35	6.8
EPS	1999 April	25	3.8
MPFP	1999 March	40	1.7
QEWS	1999 November	20	1.8
Project Support	N/A	N/A	10.6
Seismic Analysis	N/A	N/A	1.9
Safety Evaluation	N/A	N/A	3.1
Other	N/A	N/A	1.0

LESSONS LEARNED

Initial concerns about the condition of systems in a 40 year old research reactor proved to be largely unfounded. This is attributed in large part to the redundancy built into the original design that allowed for testing and maintenance, but much credit must also go to an effective aging management process applied in particular to safety critical systems. Table 3 illustrates the changes and replacements to one key system.

Table 3 NRU - Control & Shutdown System Changes as Part of Aging Management Process

Year	**Control & Shutdown System Change**
1978	• Control system vacuum tube power supplies changed to solid state.
1980	• Amplifiers in control system converted from vacuum tube to solid state. • Halon fire protection system installed in the NRU cable space.
1981	• Unit 85 high control rod drive voltage alarm installed.
1986	• Class 1 power supply batteries replaced.
1987	• Class 2 power supply Inverter C replaced.
1988	• Class 2 power supply Inverters A and B replaced.
1989	• New sequence of event recorder installed. • Trip Unit 30, Auxiliary Log Rate Instruments for channels A&B replaced.
1990	• Trip Unit 30 Auxiliary Log Rate instrument for channel C replaced.
1991	• New type UR1 control rod drive direction relay installed. • Control cables to all control rods replaced due to deterioration. • Ion chamber cable replacement program initiated. • Control system function generator magnetic amplifier power supply changed.
1992	• The magnetic amplifier replaced with equivalent amplifier as existing type is no longer available. • Air cooling provided to main control system amplifier cabinets (R-67).

Year	Control & Shutdown System Change
1993	• Control system magnetic amplifier modified. • Power supply to the control rod synchros changed. • Capacitor circuit for K-19-W-37 modified.
1994	• Magnetic Amplifier interstage power supply modified. Diodes added to protect solid state circuitry. • Pile face amplifier modified to provide overvoltage protection to solid state circuitry.
1996	• Replacement of main Class 4 power supply feeder to Building 150.

The design, procurement, installation and commissioning of the new upgrades is being done to current Canadian nuclear quality assurance standards. Fortunately these programs were already largely in place prior to the Upgrades Project; they are proving to be an essential part of the licensing process.

NRU's well defined change control process provides for a level of safety review commensurate with safety significance, is highly visible to the regulator and incorporates regulatory approvals where there is an impact on the NRU safety case. This process provides a high level of assurance and comfort that existing systems are not adversely affected and has allowed the upgrades to proceed as major modifications under the current operating licence.

The fundamental requirement that new designs should not conflict with the original safety concepts combined with strong cooperation between the Upgrade Project and NRU Operations resulted in good and practical engineering designs. These factors were critical to meeting the objective of implementing the safety upgrades to an "operating" reactor without any major outages.

Finally, in the course of the engineering assessment and the subsequent upgrade project, a number of suggested improvements were identified outside of the scope of the seven safety upgrades. These ranged from procedural changes to equipment modifications or replacements. These were submitted to the Operating group for consideration as Assessment Recommendations. To date, 41 of these recommended improvements have been completed, 16 have be rejected and 42 more are still under active consideration.

REFERENCES

[1] *Safety Assessment of Research Reactors and Preparation of the Safety Analysis Report*. IAEA Safety Series No. 35-G1. International Atomic Energy Agency, Vienna, 1994.

KEY WORDS

Upgrades, life extension, aging management, modifications, change control, research reactors, safety analysis, seismic.