SAFETY SYSTEM UPGRADES TO A RESEARCH REACTOR: A REGULATORY PERSPECTIVE

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ABSTRACT

The NRU (National Research Universal) reactor, located at the Chalk River Laboratories of Atomic Energy of Canada Limited (AECL), first achieved criticality November 3, 1957. AECL continues to operate NRU for research to support safety and reliability studies for CANDU reactors and as a major supplier of medical radioisotopes. Following a detailed systematic review and assessment of NRU's design and the condition of its primary systems, AECL formally notified the Canadian Nuclear Safety Commission's (CNSC) predecessor–the Atomic Energy Control Board–in 1992 of its intention to upgrade NRU's safety systems. AECL proposed seven major upgrades to provide improvements in shutdown capability, heat removal, confinement, and reactor monitoring, particularly during and after a seismic event. From a CNSC perspective, these upgrades were necessary to meet modern safety standards.

From the start of the upgrades project, the CNSC provided regulatory oversight aimed at ensuring that AECL maintained a structured approach to the upgrades. The elements of the approach include, but are not limited to, the determination of project milestones and target dates; the formalization of the design process and project quality assurance requirements; the requirements for updated documentation, including safety reports, safety notes and commissioning reports; and the approval and authorization process. This paper details, from a regulatory perspective, the structured approach used in approving the design, construction, commissioning and subsequent operation of safety system upgrades for an existing and operating research reactor, including the many challenges faced when attempting to balance the requirements of the upgrades project with AECL's need to keep NRU operating to meet its important research and production objectives.

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INTRODUCTION

NRU is one of the largest (135 MW_{th}) and most versatile research reactors in the world. The reactor is used for fuels and materials testing, radioisotope production and neutron scattering experiments. It is heavy water moderated and cooled but light water reflected. The core is contained in an aluminum cylinder 3.7 m in diameter and 3.5 m high. There are 227 vertical lattice sites arranged in a hexagonal array with a pitch of 19.7 cm. Fuel rods and control rods occupy about half the lattice sites; the other sites may be used for experiments and routine material irradiations. The fuel is made up of enriched uranium silicide particles dispersed in an aluminum matrix and clad in finned aluminum tubes. Two high temperature/high pressure loops pass through the reactor core but have their own independent coolant systems. These loops are used to develop and test fuels and materials for CANDU reactors.

The concept of upgrading the safety systems of the NRU reactor was first developed in the early 1990s, from discussions between AECL and CNSC staff, as a means of ensuring the continued safe operation of the facility past the turn of the century. AECL inspections and assessments revealed that the reactor facility and its critical systems were in good condition overall. However, AECL's preliminary safety assessment of the facility at that time identified specific safety concerns, resulting in the identification of seven major safety upgrades and more than 100 additional recommendations for safety system improvements. Since the planned upgrades were intended to reduce the reactor's vulnerability to common mode failures and external hazards, a grouping and separation philosophy was used. Either of the existing NRU safety systems (group 1) or the new upgrades/systems (group 2) acting alone would be capable of shutting down the reactor, ensuring fuel cooling, and confining fission product releases.

The upgrades had to conform to the following design criteria or constraints:

- complement the existing safety features of the reactor;
- be hazards-qualified;
- be installed and commissioned without extended reactor shutdowns, because of the reactor's medical radioisotope production cycle requirements;
- have no adverse effects on existing systems; and
- justify the expenditures by the safety benefit.

DESCRIPTION OF UPGRADES SYSTEMS

The seven upgrades and their purposes are as follows:

- Second Trip System (STS) – to provide a second, independent trip system separate from the existing trip and control system;
- Qualified Emergency Response Centre (QUERC) – to provide, in the event of control room unavailability, an alternate, hazards-qualified location for the initiation and monitoring of all special safety systems;
- Liquid Confinement/Vented Confinement (LCVC) – to provide a defined boundary around the reactor and the primary coolant system to confine liquid and gaseous releases under accident conditions;
- Main Pump Flood Protection (MPFP) – to protect the main heavy water pumps from flooding due to major secondary coolant leaks;
- Emergency Power Supply (EPS) – to provide dedicated, seismically-qualified emergency back-up AC and DC power to the upgrades systems;
- New Emergency Core Cooling (NECC) – to provide seismically-qualified, closed-circuit, long-term cooling of the reactor core after a loss of coolant accident (LOCA); and
- Qualified Emergency Water Supply (QEWS) – to provide a back-up source of secondary cooling in the event of a loss of the primary heat-sink.

Following are brief descriptions of the seven upgrades.

The STS provides a second independent and separate reactor trip system. The design philosophy is to maintain the existing safety and control rod systems “as is”. The STS uses completely independent and hazards-qualified trip parameters and trip logic to activate existing shutdown devices. Two new neutronic trips (high neutron power and high log rate power) and three new process trips (seismic, flooding and loss of Class IV power) provide the necessary protection.

The QUERC is a major upgrade because it provides a hazards-qualified location for the control logic of the new safety systems within NRU’s first basement and ensures a capability for post-accident monitoring of the reactor. In particular, the QUERC ensures that the reactor can be placed in a stable shutdown state and that adequate fuel cooling can be maintained. Nuclear operators would relocate to the QUERC if the Main Control Room were to become uninhabitable because of an accident.

The LCVC provides a well-defined, seismically-qualified boundary around the reactor and incorporates two major confinement features. The liquid confinement component ensures the collection and confinement of the heavy water primary coolant lost in a LOCA, which is also an essential requirement for the NECC upgrade. The vented confinement component provides for improved confinement within NRU of potential fission products and tritium vapours released from the reactor and from the liquid confinement areas such that these releases can be redirected to the reactor ventilation system.

The purpose of the MPFP is to protect emergency main heavy water pumps 4 and 5 from possible internal flooding due to large process water leaks. The main feature of the MPFP is a passive, seismically-qualified means for draining leaked process water from the NRU building at the lowest basement level, supplemented by a seismically-qualified reactor trip and shutdown of the NRU process water pumps. In particular, a drainage opening in the NRU building basement wall has been added, leading to an external culvert that permits drainage flow to lower ground. Other engineered features of the MPFP include drainage modifications within the NRU building that provide flood water drainage control routes and improved flood detection capabilities.

The EPS provides the generation, conversion and distribution of hazards-qualified emergency electrical power to the other upgrades and to primary coolant pumps 4 and 5, which are essential for core cooling with the reactor shut down. Under normal operating conditions, the EPS is supplied by the off-site electrical power distribution grid; however, EPS diesel generator units and storage batteries automatically provide alternate supplies on failure of incoming electrical power. The primary safety improvements applicable to the EPS upgrade include seismically-qualified components and support systems; multiple divisions that use separate, independent distribution systems for improved reliability; and modern equipment with fewer dependencies.

The primary design requirement of the NECC is to provide a seismically-qualified source of emergency cooling to the NRU heavy water system capable of providing, either automatically or manually, continuous cooling flow should a LOCA occur. The upgrade provides a pump-driven system that injects coolant into the emergency supply line to primary coolant pumps 4 and 5. The NECC includes two submersible pumps, pump discharge isolation and check valves, and interconnected piping to link the above equipment. The NECC equipment is located within the liquid confinement boundary of NRU. In the event of a LOCA, heavy water is recovered and collected in the NECC sump, located in the basement of the NRU building, and re-injected into the primary coolant system via the primary coolant pumps. This upgrade system is an integral part of the LCVC system and, together, these two upgrades ensure a continuous supply of coolant to the primary coolant system during LOCAs.

The QEWS provides a seismically-qualified means of core decay heat removal during loss of heat sink accidents. The QEWS is a manually-operated, closed-loop, emergency secondary cooling system. The QEWS incorporates an independent water reservoir and pumping system for post-shutdown heat removal. The key components of the QEWS are a reservoir within the basement of the NRU building, two dedicated QEWS pumps, and associated piping and valves. The QEWS supplies continuous emergency secondary cooling to main heat exchangers 4 and 5 of the emergency cooling circuits.

LICENSING PROCESS

CNSC staff included AECL's intent to proceed with the upgrades into licensing considerations early in the project (circa 1994). CNSC staff confirmed to CNSC Commission Members at that time that, upon initial review of the proposed upgrades, the concept was acceptable in principle. CNSC staff agreed with AECL that these safety system upgrades would improve on then-current facility safety systems and proposed that these upgrades be approved on a case-by-case basis following detailed staff review. This laid the foundation for future CNSC/AECL interactions throughout the project.

Following a preliminary safety review, AECL conducted a scoping assessment of the impacts of the safety system upgrades on the overall NRU safety envelope. AECL has a classification system for its change control process. Proposed changes to the facility are classified according to their safety significance. The resultant category of a change indicates the level of review and approval required. According to the *NRU Conduct of Operations Procedures*, all changes with potential impact on health, safety or the environment require review and approval by the NRU Change Control Committee and authorization by the Facility Manager prior to implementation. In addition, Category I changes require approval by AECL's Chief Engineer, approval by AECL's Safety Review Committee (SRC), and finally approval by the regulatory agency (CNSC). In general terms, a Category I change is one that "results in hazards different in nature or greater in magnitude or probability than those assessed in" AECL's licensing documents, "or which alters the design concept or design intent of structures, systems or components credited in the safety analyses … ".

As Figure 1 shows, CNSC and AECL determined early in the licensing process that three of the upgrades would encompass one or more Category I changes while the other four were unlikely to include Category I changes. The categories of changes are set out in the *NRU Conduct of Operations Procedures* and in the *NRU Facility Authorization*, both of which are AECL licensing documents.

Lower category changes, Categories II and III, do not require SRC nor CNSC approval; however, the original upgrades implementation plans specified that AECL would submit the first and final safety notes and commissioning reports to the CNSC for review. CNSC staff's comments for the lower category changes would be focussed on ensuring that the upgrade met the following licensing basis objectives:

- improve safety;
- have no unacceptable adverse effects on the existing configuration of NRU and on the other upgrades; and
- meet its performance specifications, and to be operable and reliable.

AECL committed to ensure that performance specifications included adherence to applicable standards and codes, as specified in the design requirements documents for the specific upgrade, and to the project quality assurance (QA) plan.

At the earliest stages of the upgrades project, CNSC and AECL met to discuss and ensure, from a regulatory perspective, that AECL would meet the following conditions:

- AECL had the capability and intent to continue to meet the current licensing requirements of the facility and the capability (resources, etc.) to implement the upgrades;
- the upgrades project can meet the licensing requirements (i.e., maintain or improve safety, have no detrimental effect on currently accredited safety systems, that the upgrades be reliable and operable, etc.);
- AECL's QA program meets regulatory requirements;
- the design features, safety principles, general criteria, engineering design solutions, and reliability provide confidence of reactor safety according to regulatory requirements; and
  the effects of delays in the implementation process have been adequately considered and/or counteracted.

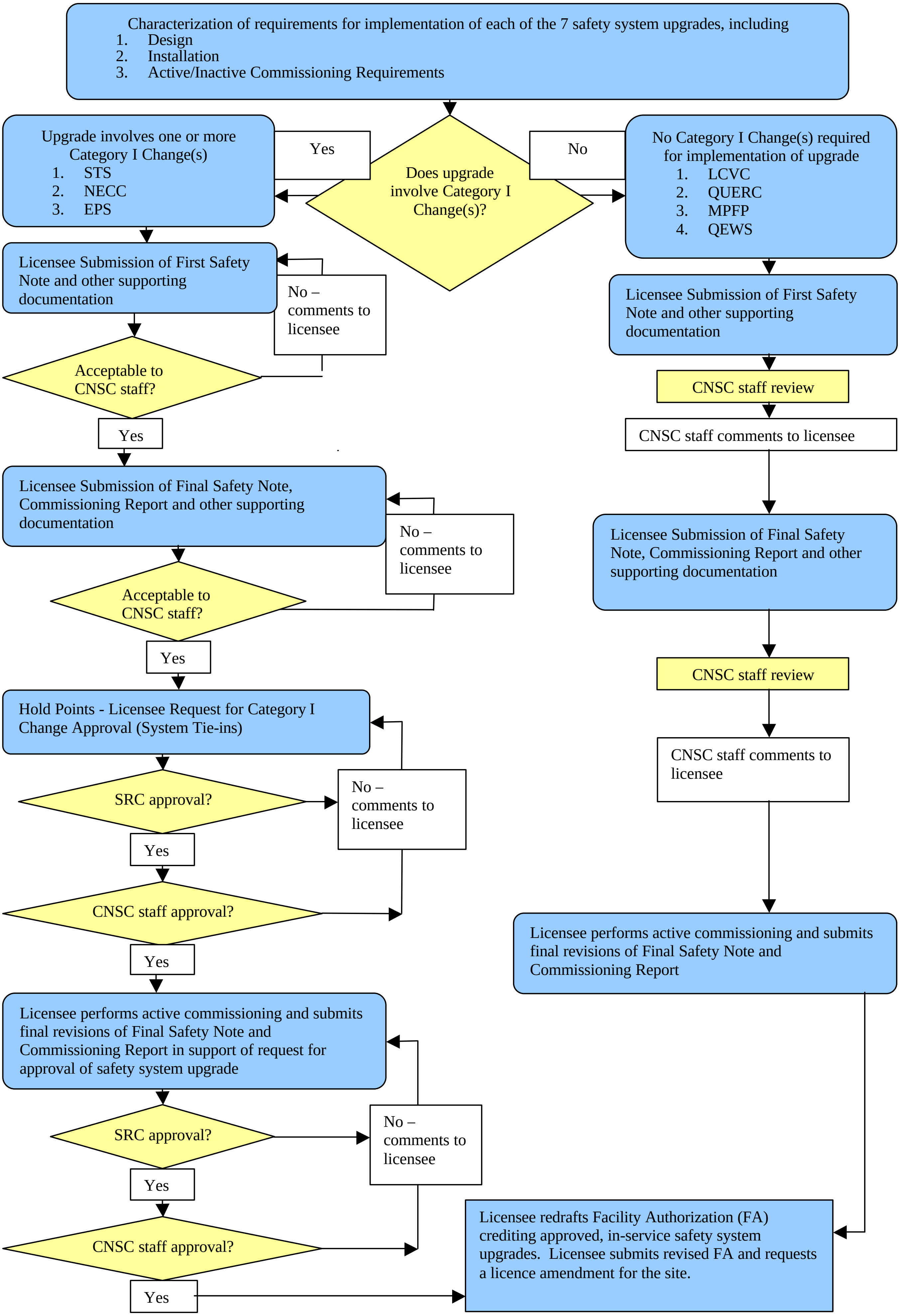

Figure 1: Licensing Process Overview

Early discussions between CNSC and AECL staff also solidified the general licensing process: the configuration changes that required CNSC approval would be requested on a case-by-case basis and the request would be for the implementation of any Category I change and for the final tie-in of the upgrade, as a safety feature, to NRU systems.

AECL would submit to the CNSC, at an early stage of a specific upgrade's implementation, a first safety note. The role of the first safety note was to describe the upgrade design; show that the implementation of the upgrade is feasible, practical and beneficial to safety; and identify the safety issues and state how these would be addressed. For the non-Category I changes, submission of the first safety note to the CNSC would be primarily for information (however, in most cases, the CNSC provided comments to AECL regarding the upgrade's likely ability to meet the stated licensing basis objectives). For Category I changes, the submission of the first safety note to the CNSC was for a more comprehensive review with a view to approving or not approving continued design, installation and inactive commissioning of the upgrade.

AECL would submit final safety notes to the CNSC later in an upgrade's implementation schedule and would incorporate previous SRC and CNSC comments. The purpose of the final safety note was to support a formal request from the facility authority for approval of in-service (active) commissioning of the upgrade and finally for approval to operate the upgrade. The final safety note would provide the as-built description of the upgrade and all required safety analyses. One or more revisions of the final safety note may have been required; however, following close-out of all outstanding issues, the final revision of the safety note would effectively close all safety issues related to the upgrade.

In conjunction with the upgrades, AECL revisited the safety analysis for NRU using modern tools and methodology. As a result, AECL wrote a new NRU safety report that also covers the upgrades. The requirement for AECL to submit a revised Safety Analysis Report (SAR) in support of the upgrade project was realized early in the project. The SAR would incorporate the safety system upgrades and be submitted for CNSC staff review in support of upgrade system active commissioning and eventual accreditation of the upgrade system in the *NRU Facility Authorization*. AECL submitted Volume 1 of the SAR, a detailed description of reactor design and operation, to CNSC staff in March 1998, and Volume 2 of the SAR, results of the detailed safety analysis, to CNSC staff in October 2000. The SAR review and approval process is ongoing with a number of action items outstanding on both parties.

UPGRADES PROJECT TIMELINE

AECL and CNSC staff agreed from the outset of the upgrades project that AECL would provide periodic update reports, with projected timelines, to CNSC staff for review. These update reports would contain timelines for completion of milestone tasks, namely inactive and active commissioning activities, submission of supporting safety documentation, tests and trials, requests for CNSC approval of Category I changes, and finally upgrade completion and issuance of completion assurance documentation.

Currently, five of the seven upgrades are in service. The others (NECC and EPS) are at an advanced stage of active commissioning. The timeline for completion of these upgrades (i.e., the safety system to be in service and completion assurance documentation issued) is May 2003 for the NECC and June 2003 for the EPS.

RELEVANT ISSUES

The NRU upgrades project was originally due to be completed, with all seven upgrades installed and in service, by 1996. The completion deadline for individual upgrade systems, and the project as a whole (including completion of the SAR), has continually been extended. The reasons for this are many, but some of them are:

- a shortage of knowledgeable, experienced AECL staff to carry out the design, analysis and construction/implementation of the upgrades;
- difficulties AECL encountered in procuring qualified components for certain upgrades;

- NRU isotope production commitments that restricted reactor shutdowns to no more than four days at a time, which made certain upgrade commissioning activities challenging;
- AECL funding limitations; and
- shifting of priorities within AECL's nuclear operations group.

CNSC resource limitations also caused some delays in achieving the two-month turnaround goal for review and submission of comments on AECL deliverables in support of the upgrades project. Furthermore, the review and approval process required that the proponents of the upgrades obtain SRC approval of safety notes before obtaining CNSC staff acceptance of them in support of active commissioning approvals, which led to some delays in the upgrades since SRC reviews and approvals were sometimes delayed, which subsequently delayed CNSC staff acceptance.

KEYS TO SUCCESS

Based on the experience of CNSC staff during this project, the following are some of the key elements required for successful completion of the implementation and licensing of a major reactor upgrade project:

- single points of contact (SPOCs) need to be designated at both the licensee's and the regulator's organizations as early as possible. This ensures that smooth, consistent communication occurs throughout the project and also that issues or concerns are dealt with expediently and effectively without numerous intermediaries. In the case of the NRU upgrades project, AECL and CNSC SPOCs were appointed early in the process, which was quite beneficial;

- a framework must be developed and formally documented at the beginning of the process to lay out
    - the lines of communication;
    - the roles and responsibilities of the key players;
    - all requisite activities that need to be addressed and commented on by both parties such that a baseline for continued progress can be established early in the project;
    - expectations in terms of deliverables, approvals, etc.;
    - configuration management issues and change control policies and practices;
    - quality assurance plans throughout the project with documented tests, results and feedback; and
    - project closure (how this will occur), including post-implementation evaluations and any follow-up actions that will take place.

  Once again, AECL and CNSC staff formalized early the project framework, containing many of the elements detailed above;

- frequent follow-up discussions need to occur to monitor progress and address issues or concerns that arise so an acceptable level of progress can continue without undue delay. Frequent discussions between AECL and CNSC staff occurred throughout the project. Projected delays in project timelines were readily communicated to and accepted by CNSC staff;

- commitment from all levels of the licensee's organization needs to be in place to ensure that continued financial and resource support is available for the project. This continued support should be formalized in writing and can be used as a licensing criterion by the regulatory agency. This proved to be one of the shortcomings of the upgrades project since competing commitments at AECL had a detrimental effect on timely project completion;

- timelines for completing project milestones need to be set and adhered to as much as possible. Written substantiation needs to be provided for the licensee's schedule to be extended, within reason, and this extension should be accepted by the regulator. The regulatory agency could consider the use of licensing penalties, e.g., shorter or more restrictive licence renewals, to deter continual project slippage. In this case, CNSC staff was apprised of and accepted significant slippage of the project schedule; however, it was not deemed advantageous to completion of the project to impose highly restrictive licensing conditions on AECL as a result of this slippage; and

- the regulator needs to clearly communicate expectations to the licensee in terms of deliverables and any follow-up inspections or audits required for the systems to be approved and accredited. Once again, this should be detailed in the preliminary project plans, developed co-operatively by both the licensee and regulatory agency. Fruitful and detailed discussions between AECL and CNSC staffs at the beginning of the project laid out expectations on each side. CNSC staff has followed up upgrade approvals with on-site inspections of the completed systems and will continue to do this in future.

CONCLUSIONS

The NRU upgrades project represents a significant and important addition to the safety envelope of the NRU reactor. The NRU upgrades are designed to bring the reactor to a safe shut-down state under a variety of abnormal situations. Currently, five of the seven upgrades have been installed and are in-service with the remaining two upgrades scheduled to be completed and in-service by June 2003. Early in the project, a structured, formalized framework was developed involving a series of critical hold-points requiring CNSC approval prior to continuation. Co-operative, continual CNSC and AECL staff interactions from the early stages of the project have had a net positive effect on the implementation of the upgrades to date. A number of relevant issues and keys to success have come to light, namely the importance of long-term financial and resource planning and commitment for the project from the licensee. CNSC staff recognizes that acceptance of project deadline extensions must be balanced with competing issues; yet all decisions must ultimately assure that safety upgrades are successfully implemented with minimal delay.