CANDU™ 6 Refurbishment and Optimization of Radiation Protection

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The refurbishment of the CANDU™ 6 reactor at Point Lepreau Generating Station involves a large-scale replacement of the reactor core fuel channels, calandria tubes and associated feeder pipes. The majority of the work is carried out within the reactor vaults and fuelling machine maintenance locks. One of the main concerns, from an ALARA[1] point of view, is the background radiation field to which personnel working in the vaults, at the reactor face, and at the feeder regions are continuously exposed.

The principle of ALARA is based on the trade off between dose, social and economic factors. Putting the elements of ALARA into practice requires complex analyses, common sense and judgement as well.

In applying the ALARA principle, Atomic Energy of Canada Limited (AECL) has used strategies to reduce external/internal dose including: reduce source of radiation (radioactive decay, temporary shielding or shielding incorporated into tooling); minimize time spent in a radiation field; maximize distance from the radiation source; contamination control; planning and optimization of the work process; training (radiation protection and mock-up trainings) and waste management and public safety concerns.

ALARA measures practiced through: Radiation Exposure Permits (REP) and Pre-Job Briefs (PJB) for work <0.020 person-Sv and REPs, PJBs and ALARA Plans for works >0.020 person-Sv.

Lessons were learned from the first CANDU™ 6 refurbishment operation[2]

1. INTRODUCTION

The Point Lepreau Generating Station (PLGS) is a 680 MWe facility that was commissioned into service in February 1, 1983. With a lifetime capacity factor of 82.4%, it has safely generated electricity for the people of New Brunswick, Canada for more than 25 years.

The Point Lepreau Refurbishment (PLR) Project is the first CANDU[3] 6 reactor to be refurbished. During the refurbishment project, all 760 feeder pipes and 380 fuel channels and components are replaced. Improvements to the Primary Heat Transport (PHT) system and the moderator system are also being implemented as part of the scope of this project.

1.1. An Introduction to CANDU Reactor Design

CANDU (Canada Deuterium Uranium) is designed by AECL. The CANDU reactor is a pressurized heavy water reactor that uses heavy water (deuterium oxide) for moderator and coolant, and natural uranium for fuel. CANDU 6 reactors are used to produce isotopes and electrical power in several countries. There is currently a fleet of 32 CANDU reactors in operation that 11 of them are the CANDU 6 design.

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[1] As Low As Reasonably Achievable (ALARA)

[2] © Atomic Energy of Canada Limited, 2009.

[3] CANDU is a trade-mark of Atomic Energy of Canada Limited (AECL).

In the core of a CANDU reactor the cooler-low pressure moderator is separated from the hot pressurized primary heat transport coolant.

The moderator is contained in a vessel called the calandria while the primary coolant and fuel bundles are contained in a number of identical horizontal fuel channels (380 in CANDU 6). An annulus provides a thermal barrier between the pressure tubes and the calandria tubes.

A significant design feature of the CANDU[4] reactor is that it permits refuelling of the reactor while it is operating at full power. It can contribute to the high net capacity factor of CANDU plants by eliminating the need for reactor shutdowns to replace fuel.

1.2. Refurbishment Work Scope

In order to extend the operating life of Point Lepreau for another 25-30 years an extensive scope of work was developed to refurbish or replace various components throughout the nuclear and conventional sides of the station with modifications to bring it up to today's standards.

The replacement of various components, defined as "retube" operation, is broken down into the five phases listed below. Each phase is composed of a number of activities referred to as a series.

- Retube Support operations
- Feeder Removal
- Fuel Channel Removal
- Fuel Channel Installation
- Feeder Installation

Refurbishment of, and improvements to, the PHT system, the moderator and auxiliary systems, and the safety systems, are defined as "refurbishment" in the work scope.

2. POINT LEPREAU REFURBISHMENT (PLR) PROJECT AND PUBLIC SAFETY

New Brunswick Power Nuclear (NBPN) complies with all applicable environmental legislations and other non-regulatory commitments at its facilities, from early planning through operation and finally decommissioning. According to the Canadian Nuclear Safety Commission (CNSC) regulations, releases of airborne radioactivity and radioactive liquids shall be controlled and monitored continuously[5].

Proper ventilation is necessary to maintain a safe and comfortable workplace. However, the ventilation exhaust is a significant pathway for the release of radioactivity to the environment.

Consequently, the exhaust systems for Zone 3[6] areas contain various filters to remove contaminants prior to release. Emissions are controlled through stack monitoring and operational procedures.

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[6] Zoning is the classification of an area according to its potential for a contamination hazard. There are three zones at PLGS'. Zone 3: contain radioactive systems/ materials that may cause contamination; Zone 2: contain no radioactive systems and normally free of contaminations but there is potential for contamination due to people traffic and ventilation flows; Zone 1: absolutely no contamination is permitted.

All of the "active" sumps are directed to the liquid waste tanks. Inactive sumps may be diverted on occasion. All liquid effluent leaving the station via the liquid waste management system is monitored prior to and during the discharge.

2.1. Radioactive Effluent

Radioactivity in airborne effluents from PLGS for the years 2007 (before the project starts) and 2008 averaged a dose of 0.61 μSv (2007) and 0.38 μSv (2008) to the public at 1 km from the station.

Radioactivity in liquid effluents for the years 2007 and 2008 averaged a dose of 0.19 μSv (2007) and 1.4 μSv (2008) to the public. The increase in liquid releases in 2008 occurred in the third quarter of the year and was due to flushing of the moderator system after draining the system's heavy water to storage tanks. Two light water flushes were made to remove heavy water trapped within the lines.

2.2. Waste Management

The PLGS Solid Radioactive Waste Management Facility (SRWMF) Phase III provides a safe and retrievable storage for solid radioactive components removed from the reactor.

The Phase III Facility within the PLGS SRWMF contains two types of waste storage structures: waste storage vaults and retube canisters. Each structure type is designed to effectively contain a particular waste, to prevent contact of the waste with precipitation and ground water, and to maintain external radiation fields below 25 μGy/h on contact with the exterior of the structures.

All areas inside Phase III buildings, inside the Phase III fence and the top of the canister shall be considered Zone 2. The inside of all storage structures shall be considered Zone 3 once radioactive waste is stored inside the structure. No loose contamination is permitted outside the storage areas.

The Large Waste Transfer Flask (LWTF) and Small Waste Transfer Flask (SWTF) that contained the End Fittings (E/F) and the Pressure Tubes (PT) and Calandria Tubes (CT) coupons (PT's/ CT's removed from reactor and crushed into coupons) are checked for loose contamination and radiation fields prior to removal from the protected area to the SRWMF. There is zero tolerance for loose contamination outside the protected area. The target dose rates for transport flasks are specified as 250 μSv/h on contact and 25 μSv/h at 1m from a transport flask.

Radioactive Waste Transfer Release forms must be completed for each waste transfer to the Phase III facility[7].

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Transportation and storage of solid radioactive waste in the Phase III Facility is performed under a strictly defined-detailed procedure to protect the workers and the public from any harm. The procedure states:

- During transfer of radioactive waste to the Phase III facility, all other traffic shall be controlled by Security to ensure that no other vehicle is encountered en route[8] on the newly constructed road to the SRWMF[9].
- During storage of waste, radiation fields at working levels should be maintained at the lowest possible level, following the principle of ALARA.
- Loose contamination is not permitted because of the direct route to the environment. During waste handling operations, monitoring shall be performed at the work location boundary to ensure that contamination is not spread within the facility.

3. RADIOLOGICAL CONCERNS FOR PLR PROJECT

Refurbishment of the PHT system required the system, which carried and circulated the heavy water coolant through fuel channels for 25 years, to be drained, bulk dried and then removed. The hazards of airborne tritium and particulates were expected.

There was a chance of airborne tritium and particulates when the 380 fuel channels were removed, and volume reduced into coupons. High γ- rays and hot particles were likely.

3.1. Ambient Radiation Field

The majority of the PLR refurbishment activities have been carried out from the reactor vaults and fuelling machine maintenance locks. From an ALARA point of view, one of the main concerns was the background gamma dose rates at the vault floor, the reactor face, and the feeder regions, to which the personnel working at these locations have been continuously exposed.

3.2. Open Beam

The fuel channel removal, inspection and installation operations are expected to be associated with some reactor configurations, which necessitate an open beam on the work platform.

To protect workers from the high radiation field of an open beam, the Lattice Sleeve Handling Tool (LSHT) are designed and procured.

The LSHT installs the thumbtack containing a temporary shield plug into the lattice tube after the E/F is removed to suppress the beam[10].

To have access to lattice sites to remove and install fuel channel assemblies and CTs, the LSHT removes the thumbtacks and temporary shield plugs and then reinstalls them after the work is completed. Operating an LSHT requires minimum operator interface. The tool is operated via a pendant from a “safe distance”.

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8 The route is closed to the public.

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10 To have access to lattice sites to remove the fuel channel and the CT, the temporary shield plug was removed by the LSHT and then reinstalled. For inspection series and the CT install, thumbtack is out and back by the LSHT. For PT install thumbtack and temporary shield plug are removed by LSHT.

Some safety features (e.g. long handles) have been incorporated into the retube tooling designs in order to protect workers from open beams.

Procedural requirements, and direct support from a Protection Assistant (PA), protect workers from receiving an inadvertent dose from the open beams.

3.3. Airborne Hazards

When neutrons irradiate heavy water (D_2O), some of the deuterium atoms (D) in the D_2O, absorb neutrons and, by an (n, γ) reaction, they become tritium atoms ($_1H^3$, H-3, or T).

There would then be water molecules in which one of the D atoms has become a T atom, and these molecules would be TDO instead of D_2O molecules. TDO is tritiated heavy water and is produced whenever the moderator and/or PHT heavy water is in the core.

Whenever moderator or PHT heavy water is exposed to air, some of the heavy water and the tritium it contains will evaporate and cause an airborne tritium hazard[11].

During feeder removal, when feeders are cut and packaged in waste containers, activated corrosion products deposited in the feeder pipes are released into the vaults as dust. This dust, whether dispersed in the air or deposited on surfaces, is an airborne hazard.

PTs and any associated garter springs and CTs are removed and volume reduced by a machine called Volume Reduction System (VRS). In such a procedure, there is a chance that highly activated particles escape from VRS and are dispersed in the air or deposited on surfaces.

4. ALARA PRINCIPLE A TRADE OFF BETWEEN DOSE, SOCIAL AND ECONOMIC FACTORS

The ALARA principle that means establishing doses as low as reasonably achievable with consideration of social and economic factors has been applied throughout the development and implementation of the PLGS refurbishment project.

Radiation protection optimization for the project began with the design and planning of the work. It continued with design and procurement of the tools, scheduling and developed throughout the implementation and feedback stages.

A Construction History Package (CHP) document reports the history behind each retube series and each “refurbishment” activity that was implemented. This CHP document comprises Construction Work Package (CWP), Detailed Work Instruction (DWI) and ALARA Plan.

The optimization for some of the operations was developed when the radiological conditions of the work changed. For example, through the PT removal, the ALARA Plan was revised and re-published in several revisions.

In some cases when some protection measures were not required any more, i.e. access control or tritium respiratory protection, then the ALARA Plan based on the new requirements was revised and re-published[12].

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[11] A beta particle has to have the energy of at least 70 KeV to be able to penetrate the dead surface layer of the skin. Therefore, tritium is not an external hazard, only when it is taken into the body it will be able to irradiate live tissue. Tritium has a half-life of 12.3 years.

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The optimization is a dynamic practice that is constrained by the ALARA principles and the production level.

5. AECL'S ALARA STRATEGIES FOR PLR PROJECT

AECL's strategy to implement ALARA is established on the principles of: 1) designing work practices; 2) identification of hazards and dose assessment; 3) modification to tooling design considering the ALARA tools of distance, time and shielding; 4) procedural control of operations.

5.1. Designing Work Practices and ALARA Decisions

AECL was contracted by New Brunswick Power to provide complete project management, design, and procurement and installation services and implement the large-scale refurbishment project.

The contract calls for a two-phase program. Phase 1 comprises of a preliminary engineering feasibility study for the PLR project. Phase 2 consists of a detail design and procurement of the tooling, design and procurement of new components for the reactor and implementation of the retube and the "refurbishment".

In the early planning stages of the project, major engineering decisions with profound dedication to ALARA principle were made. Some of these engineering decisions are described below:

(a) PHT System Bulk Drying

Bulk drying of the PHT system was designed to remove residual tritium from the system after it was drained off the tritiated heavy water (coolant).

The benefit of this effective drying is that, as a general rule, there is no requirement for workers to wear plastic suits for protection against tritium. The plastic suits are used selectively, as appropriate, to address specific work or the start of a sequence until the tritium hazard can be confirmed.

(b) Feeder Removal from Partial Feeder Removal to Total Feeder Removal

The initial intent was to replace the lower feeders up to the first bend where Flow Assisted Corrosion (FAC) was observed (partial feeder removal). Further investigation and evaluation showed that a prudent approach would be total feeder replacement. Total feeder removal would eliminate any risk from unidentified areas of upper feeders susceptible to FAC in future operations. Also it would remove the risk to accelerated corrosion of old feeder material in future, since new feeder material would be implicitly less susceptible to FAC. Based on this rational, the decision was made to remove the total feeder pipes.

From a dose perspective, the total feeder removal, has reduced the dose rates in the vaults and in the fuelling machine maintenance locks that means a significant dose saving for the subsequent activities in these areas.

The decision will also reduce any risk of future outages for feeder repair work. Thus, from an ALARA perspective total feeder removal is the preferred option[13].

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(c) Timing of Feeder Removal

The project decided to remove the feeders at an early stage of the outage. This decision ensured that the dose rates from the activity deposited in the feeders would be eliminated for all subsequent work in the fuelling machine vault.

Deposits of Co-60 with its 5.3 years half-life dominate the dose rates in the fuelling machine vaults. The deposits of the shorter-lived Zr-95 (64 days half-life), and its daughter product Nb-95 make a smaller contribution to dose rates. A delay of six months achieves less than a two-fold reduction in dose rates. Since the schedule for the refurbishment project was about 18 months, deferring feeder removal to allow some decay of the deposited activity was impractical. Thus from an ALARA perspective an immediate removal of feeders was a preferred option.

(d) Removal of Adjusters from the Reactor Core

The impact on radiation fields resulting from having the stainless steel adjusters inside the core was extensively examined by AECL.

The study showed that having the adjusters in the core would result in a significant increase in radiation fields at the front of the reactor faces (dose rates at the front of the fuel channel work platform would increase by up to a factor of 20).

Open beam dose rates were calculated to be between 1500 mSv/h and 3000 mSv/h depending on the reactor configuration, while dose rates without the adjusters were calculated to be between 80 mSv/h and 300 mSv/h.

Although procedural constraints and radiation shielding ensure that operators are kept out of open beams at all times, in case of an inadvertent exposure to an open beam (even if it is in the periphery of the beam) a significant dose will be taken.

AECL recommended removing the adjusters from the reactor core as early as possible before the fuel channel removal.

The adjusters were removed and since then they have been parked in their positions and will remain there until the moderator is refilled (after calandria tube installation and rolled joint leak testing).

5.2. Identification of Hazards and Dose Assessment

Preliminary design concepts were established, and the activities and tasks associated with retubing and “refurbishment” were proposed. To compliment the design work, a Preliminary Process Hazard Analysis (PPHA) of retubing and “refurbishment” activities was undertaken as outlined in the Health, Safety and Environment (HSE) Work Activity Plan. To facilitate this PPHA requirement, AECL led a 5-day workshop session with discipline experts from both AECL and NBPN as the initial step in a broad assessment of the hazards associated with their retubing and “refurbishment” activities.

A second Hazard Analysis (HA) workshop was held approximately one year later to review all retube activities and ensure that the hazards and recommendations identified in the first workshop, were addressed and incorporated into the design of the work[14].

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Additionally, for retube operations that were not reviewed or had changed since the first workshop, a re-evaluation was done to assess all potential hazards.

AECL prepared dose assessment reports as the project proceeded. The personal and collective dose evaluations were performed by the radiation protection group in collaboration with the design engineering group. The results were utilized for the work process and tooling design.

5.3. Modification to Tooling Design Considering ALARA Tools of Distance, Time and Shielding

An ALARA Tool Design Guide provides the general guidelines for tooling designs based on the AECL/ NBPN radiation protection requirements and the ALARA tools of time, distance and shielding.

AECL performed an extensive analysis study to estimate the dose rates for the retube series by simulation of various configurations of the reactor for different retube activities. The results of these analyses were used in the design of new or modified tools.

The retube tooling is comprised of long handled manual tools, automated tools or tools that are operated from a “safe distance”. Where human interface with the tooling is required, shielding walls are added to the work platforms to provide workers with a low dose area where they can wait until the next intervention.

During the fuel channel removal operation, the entire E/F, complete with the irradiated shield plug and the temporary closure plug are removed as a single unit. The PT cutting operation leaves a small portion of the PTs attached to the inboard end of the E/F. This small portion of PT is highly radioactive, and along with the irradiated shield plug, presents a significant radiation hazard. Following E/F removal, specifically during PT and CT removal, transient high radiation fields exist on the annulus gas bellows. To reduce these radiation fields, steel plates, referred to as lattice sleeve side shields are installed on the peripheral lattice sites.

These side shields are installed to provide shielding on the bottom and sides of the lower half of the peripheral lattice sites and the sides of the upper half. This is one example of shielding design with respect to ALARA.

5.4. Procedural Control of Operations

AECL has been utilizing a multi phase process to ensure that workers are fully prepared with the procedural knowledge to conduct their work while avoiding an unnecessary dose.

5.4.1 Training

All personnel working at PLGS receive basic conventional and radiological safety training consisting of classroom training and field tours to provide workers with a good practical knowledge of the environment in which they are working. They are advised of the risks of working in a radioactive environment and receive instructions about monitoring requirements and personal protective equipment usage. At the basic level they are not permitted to perform any radioactive work without the direct oversight of radiation protection personnel[15].

[15] © Atomic Energy of Canada Limited, 2009.

Series operations are practiced on mock-ups to increase efficiency, thus reducing the retubing duration and dose received by workers. In mock-up practices the related DWI steps are to be thoroughly rehearsed. A Radiation Protection expert attends the mock-up training to evaluate the radiological aspects of the work. The feedback from the mock-up practices is applied to modify the DWI steps, the estimated dose in the REPs, and it also identifies the ALARA measures for the ALARA Plan. Workers are also trained in practical matters, such as how to dress and undress in protective clothing to avoid being contaminated.

PAs are trained to a level where they are responsible for the radiation protection of workers who have received basic training. They are familiar with the radiation protection procedures. They are trained to perform surveys, assemble and dismantle contamination control areas (rubber areas), survey and tag radioactive material and survey, tag and complete release permits. The most important part of their responsibilities is to keep workers' dose ALARA, themselves included. They do this by monitoring workers' dose, identifying opportunities for dose rate reduction (source term removal or use of temporary shielding), keeping workers out of open beams and by taking every opportunity to keep workers in low dose areas whenever possible.

5.4.2 Radiation Hazard Assessment Checklist

The process begins with a thorough review of a CWP by radiation Subject Matter Experts (SME). The SME's inputs, a radiation hazard assessment checklist and an ALARA Summary become a section of each CWP.

Each CWP team provides all relevant input, which then gets incorporated into a DWI. This DWI document, once reviewed and approved, then becomes the document of record of the construction work.

5.4.3 Radiation Exposure Permit (REP)

All work assigned within PLGS radiation areas must be reviewed and a dose assigned. A REP is created for each job and the dose is assigned by considering the radiation fields, the airborne hazard rate and the number of workers involved.

Mock- up training for each task determines an optimum number of the workers required.

The process to create a REP must be thorough and all-inclusive to ensure that all possible sources of dose are considered. Dose and the dose rate alarm set points are set in Personal Alarming Dosimeters (PADs) based on the REP.

5.4.4 ALARA Plan

ALARA plans are provided where the collective dose for a task is expected to exceed 0.020 person-Sv or when tooling/equipment is inserted into or removed from the reactor. ALARA Plans provide a brief description of the work, the hazards and the protective measures to keep worker dose ALARA. The plan needs to be followed during the task implementation[16].

5.4.5 Pre-Job Briefs

Pre-job briefs provide the opportunity for three-way communication to take place.

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That is, hearing the information, repeating it for clarification and then receiving confirmation that it is correct. Three-way communication ensures understanding of the job procedure, expectations and the associated risks, as well as what to do in under PAD alarm conditions.

6. MEANS OF REDUCING EXPOSURE

AECL and NBPN put much effort to work safely according to all regulations. The AECL/PLGS Health Physics, Radiation Protection and ALARA groups conduct these efforts. OPEX, innovation and learning are the main means of reducing exposure to workers.

6.1. Direct Protection-PA support

The Radiation Protection Supervisor decides the method of protection. PAs provide direct support for high risk/high dose radioactive work.

Work on the reactor face, moderator system and steam generator (primary side) are examples of where direction protection is required.

6.2. Indirect Protection

Indirect protection is used to provide radiation protection to workers in low dose rate areas where there is no risk of changing radiological conditions and low dose rates. PADs will warn workers if they get into an area where the dose rates are beyond what they are permitted to work in. If this occurs they need to back out and get assistance from a qualified PA.

(a) Personal Protective Equipment (PPE):

Respiratory Protection: Respirators are used to protect against internal uptakes. Workers must be “fit tested” to ensure a proper respirator seal for tritium and particulates.

(b) Contamination Control/Rubber Area:

In an attempt to control contamination at the source, contamination control areas or rubber areas are set up. Workers are trained to don and doff and must wear anti-contamination clothing when working in a rubber area.

Direct PA support is required to “frisk” workers when they exit to ensure they have not become contaminated. Hand and foot monitors are set up at various locations for workers to monitor prior to leaving the areas. Whole body monitors are provided at zonal boundaries.

(c) Active Ventilation System (AVS):

The Active Ventilation System controls the spread of radioactive particulate contamination that is either airborne or has the potential to become airborne during the retube activities inside the Reactor Building. The D2O Vapour Recovery System provides the general ventilation for work areas.

The spread of the airborne debris is controlled by local ventilation systems that capture the potential airborne contamination at the source before it can spread throughout the work areas. The air from the local ventilation system is subject to HEPA filtration and is exhausted to the D2O Vapour Recovery System[17].

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[17] © Atomic Energy of Canada Limited, 2009.

(d) Exposure time/ Low dose Area:

Tools such as mock-up training, pre-job briefings, ALARA Plan reviews and direct PA protection are used to reduce exposure time. This is augmented by having workers in a "designated low dose area" as much as possible.

(e) Temporary Shielding:

Temporary shielding is used extensively to reduce dose rates. Prior to the work beginning PAs survey the work site and recommend opportunities for temporary shielding. Hot particles are removed to shielded flasks.

(f) Work Area Surveillance (AAGM, AATM, CAM, Closed circuit monitoring):

Alarming Area Gamma Monitors (AAGM), Area Alarming Tritium Monitors (AATM) and Continuous Air Monitors (CAM) are monitored by the dose control operators 24/7 to ensure workers are protected against changing conditions.

(g) Decontamination of Work Area and Equipment as Work Progresses:

Rubber areas are monitored on a routine frequency to ensure that contamination is controlled. Equipment leaving a rubber area is monitored to ensure it is contamination free or wrapped to contain contamination.

(h) Access Control:

Access control restricts access to a radioactive work area where conditions could change due to the nature of the work. For example, the reactor vaults were restricted to personnel involved in pressure tube removal while that work was in progress.

(i) Shift Logs:

The logs of both the Radiation Protection Supervisor (RPS) and Lead Protection Assistant (lead PA) are important tools to ensuring information is turned over from shift to shift.

Some examples of items logged are; contamination events, survey results, changes to the access control plan and approved changes to the ALARA Plans. Items that are carried over through all crews are added to the log summaries for crew consistency.

In addition to the RPSs and Lead PAs, access to review these logs is given to both AECL and NB Power health physics, NB Power Radiation Control, AECL Radiation Control, Station Management and the regulator, CNSC.

(j) Dose Control Centre (DCC):

PAs are dispatched, and dosimetry, communication equipment, survey instruments, and radiological advice are distributed from the dose control centre. Workers' PADing in and out are controlled in DCC.

(k) Audio Visual Telecommunication System (AVTS):

This system is used by the PAs to monitor the radiological conditions where the work is being performed. Workers wear Personal Alarming Dosimeter (PAD), "teledosimeters", which transmit dose and dose rates in real time to the AVTS operator[18].

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[18] © Atomic Energy of Canada Limited, 2009.

(l) Retube Operation Centre (ROC):

Critical work is directed (DWIs) and quality assurance observed from the ROC. ROC operators ensure procedural compliance through 3-way communication. There is a communication link between the ROC and AVTS operators to ensure worker dose is kept ALARA. ROC will identify to the AVTS operator when a work step in the DWI will significantly change the radiological conditions. This information is then passed on to the PA in the field.

7. OPEX

The collective dose received by the retube and "refurbishment" operations to the time of writing of this paper is presented and compared with the planned dose in Figure 1. There are some discrepancies between the planned and the actual dose for some operations. These were the challenging periods of the retube series.

7.1. Major Milestone Affecting ALARA

2008 May 30: Reactor vaults turned over to AECL to begin PLR project execution.

2008 September: PHT system (Feeder Pipes) was removed. This removal resulted in a large-scale source term removal from the reactor vaults.

2009 February: E/Fs were removed. A large-scale source term removal from the reactor face occurred.

2009 April: PTs were removed. It was the first time that the automated VRS tool was used and highly radioactive and contaminated components; PTs, were removed from the reactor core.

These were challenging operations from the ALARA perspective.

7.2. Analysis of Actual Dose Versus Planned Dose

Collective dose for the first four months is greater than anticipated due to the fact that the dose rates in the feeder cabinets and on the face of the reactor are slightly higher than anticipated and time spend on the initial series in these higher dose rates is greater than that is planned (Figure 1, Ref. A).

Collective dose for January 2009 to March 2009 was lower than planned due to the reduction in source term when the removal of the E/Fs was taking place (Figure 1, Ref. B).

Collective dose in April 2009 and July 2009 was higher than planned due to unplanned high dose intrusive work inside the VRS system and maintenance activities (Figure 1, Ref. C).

7.3. Contingency Plans

Contingency plans have been developed in the event of tool failures. Tooling subject matter experts and engineers have developed these plans. Both AECL and PLGS radiation protection specialists completed an extensive ALARA review prior to the plan being issued for use[19].

For example, the series with the greatest risk of personnel exposure and the release of radioactive contamination was the removal of 380 highly radioactive pressure tubes from the reactor core.

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Remotely the tubes were cut then extracted to a VRS where they were volume-reduced into coupons to reduce the size and volume of the radioactive material. This material was dropped into heavily shielded flasks and removed for disposal at SRWMF. During crushing the tubes into coupons, they were shattered not only in the press area, but also in the area that feeds the press. The source term quickly built up in the feeder area affecting the general dose rates on the work platform. Shielding was added to reduce the fields while a plan was developed to remove this material from the feeder and place it in the flask. Workers wore anti-contamination clothing and respiratory protection while using cameras and long handled tooling to remove the debris in an effort to keep worker dose ALARA.

7.4. Tooling Modification

While removing primary heat transport cooling water piping (feeders) in a high dose rate area it was discovered that the designed tooling was taking too long.

In an effort to reduce worker exposure by reducing time, new tooling was introduced. The increased risk to contamination control was the trade off to reducing worker dose. Once the huge source term from the feeders was removed contamination released during this series was cleaned up.

Due to requirement for human interface at regular intervals during E/F removal the original design of the tools had the operational pendants attached to the side of the tooling.

Responding to OPEX with ALARA in the forefront a shielding wall was designed and installed further away from the tooling on the work platform. Longer cables were installed on pendants to permit operation in a lower dose rate area.

Prior to PT removal the requirement for human interface decreased and the pendants were moved behind the shielding wall in the reactor vault. This strategy was carried into future series.

7.5. ALARA Plan Revisions

ALARA plans have been under constant review to look for dose savings from our own OPEX as the series progressed. For example, prior to pressure tube (PT) removal, dose rates in various areas around the work platform and the VRS while PT removal was in progress were not clearly understood. Remote area monitors were set up to obtain area dose rates. Access control was put in place to restrict personnel access to these radiological work areas. Once the dose rates were analysed access control was re-evaluated and modified, and the ALARA plan was updated.

7.6. Post Series Review

At the end of each series extensive reviews are completed to ensure OPEX and ALARA strategies (that are incorporated into ALARA Plans) are carried forward not only into the remaining series but also to the next project.

From a radiation protection/ALARA point of view these reviews contained dose rate measurement data, radiation exposure permit reviews, dose targets and actual dose expenditure, successes and areas for improvement[20].

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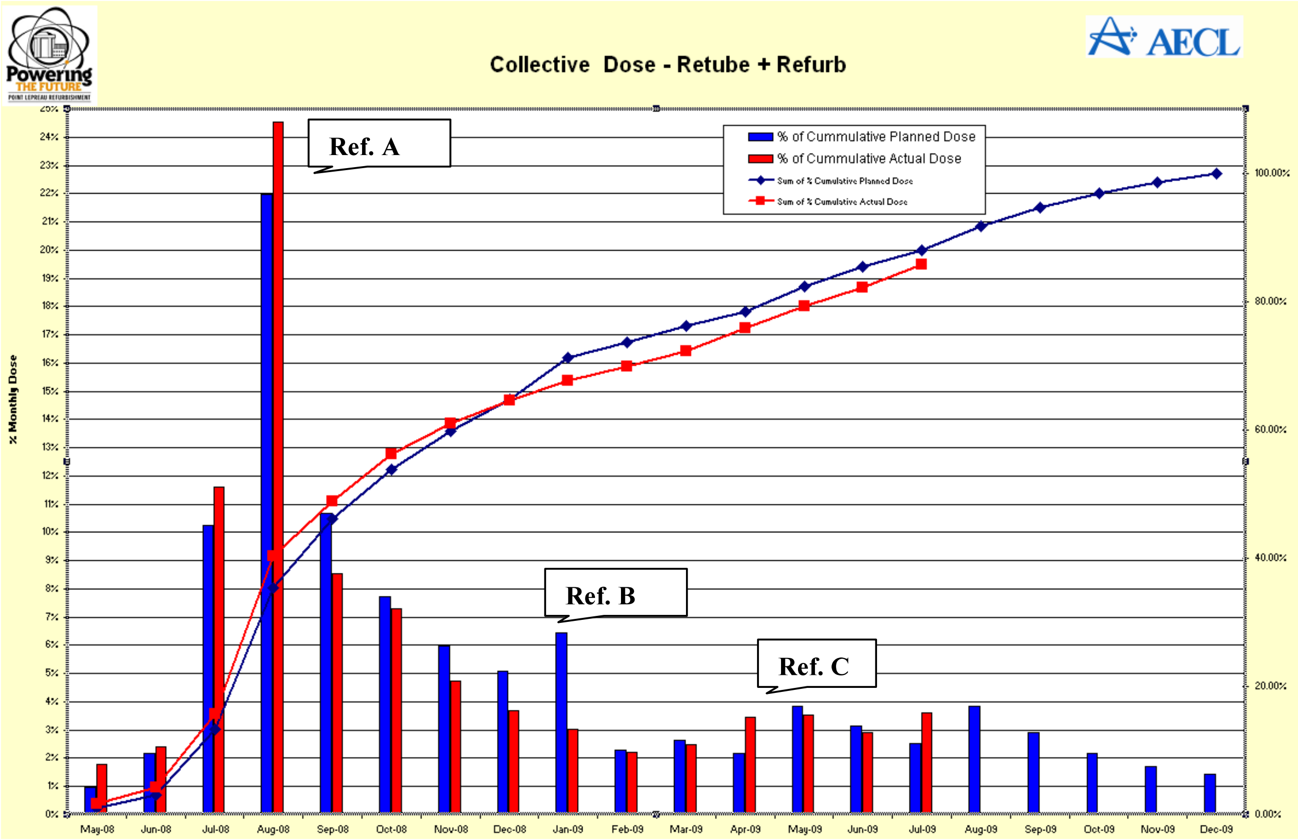

Figure 1 Monthly Actual Dose vs. Planned dose for Point Lepreau Refurbishment Project

8. SUMMARY

The AECL Point Lepreau Refurbishment execution started on May 30, 2008, when the reactor vaults were turned over from NB Power to AECL. It was soon realized that, to be successful in such a massive project, a team effort between the two organizations would be required.

The practice of optimization that began in the early stages of engineering decisions has been carried out through the tooling design and procurement, and implementation. It will continue until the breaker is closed and the steady stream of reliable power once again flows through the transmission lines to the people of New Brunswick.

Optimization in practice is the most important part of dose reduction, because reliance on the regulatory limits is not enough to achieve an acceptable level of protection and work ALARA.

AECL has created ALARA plans for the retube series and the “refurbishment” work involved with PHT and moderator systems. Other than the general requirements that each ALARA plan has, these plans have put more restrictions proportionate with the hazards expected from that specific task. They also provide more specific guidelines[21].

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In practice, ALARA principles for the refurbishment are not limited to regulatory limits (individual dose constraints) with respect to radiation work, or in how to follow the radiation protection procedures, or what PPE should be used and how or/if a PA is required to reduce the dose to a lower level.

ALARA during the refurbishment has been a safety culture that has been implemented by all workers who have been involved in the project. This culture is rooted in the instruction of "STAR": "Stop, Think, Ask, Review".

On account of this safety culture, the refurbishment has achieved 2,790,295 [22] Person Hours without a lost time injury or an over dose incident.

As in all projects of this magnitude there have been many challenges along the way and many more to come[23].

9. ACRONYMS

AECL	Atomic Energy of Canada Limited
REP	Radiation Exposure Permit
PJB	Pre Job Brief
PLGS	Point Lepreau Generating Station (PLGS)
PLR Project	Point Lepreau Refurbishment Project
PHT System	Primary Heat Transport System
NBPN	New Brunswick Power Nuclear
CNSC	Canadian Nuclear Safety Commission
SRWMF	Solid Radioactive Waste Management Facility
LWTF	Large Waste Transfer Flask
SWTF	Small Waste Transfer Flask
EF	End Fitting
PT	Pressure Tube
CT	Calandria Tube
LSHT	Lattice Sleeve Handling Tool
PA	Protection Assistant
CHP	Construction History Package
CWP	Construction Work Package
DWI	Detailed Work Instruction
FAC	Flow Assisted Corrosion
PPHA	Preliminary Process Hazard Analysis
HSE	Health Safety Environment

[22] At the time of writing of this paper (2009 August)

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HA	Hazard Analysis
PAD	Personal Alarming Dosimeter
PPE	Personal Protective Equipment
AVS	Active Ventilation System
DCC	Dose Control Centre
AVTS	Audio Visual Telecommunication System
VRS	Volume Reduction System
ROC	Retube Operation Centre

10. REFERENCES

[1] Safety Reports Series No. 21, Optimization of Radiation Protection in the Control of Occupational Exposure, International Atomic Energy Agency, Vienna, 2002.

[2] NBPN, unpublished procedures.

[3] AECL, unpublished documents[24].

24 © Atomic Energy of Canada Limited, 2009.