Radiation Protection Aspects of AECL's Retube/Refurbishment Projects

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In contrast to the construction of a new nuclear reactor, Retube/Refurbishment of nuclear reactors that have been in operation for many years will involve fabrication of a new core in a radiation environment. Careful planning of the radiation protection (RP) program is crucial to ensure the protection of workers and the environment, and the success of the projects. This paper describes the key RP activities currently underway in AECL's Retube/Refurbishment projects, covering RP during retubing tooling and system designs, retubing work planning, retubing operation, and waste transfer and management. The discussion will focus on RP initiatives from engineering design aspects of the projects.

1 Introduction

Retube/Refurbishment of the existing reactors to extend their operating lifetime for another 25 ~ 30 years is economically appealing for CANDU®. reactors. Currently, AECL is contracted to retube Bruce A, Point Lepreau Generating Station, and Wolsong 1 station. Other potential Retube/Refurbishment projects in the future include Gentilly-2, Embalse and Pickering B.

Retube/Refurbishment of a CANDU® reactor involves replacement of the fuel channel components of the reactor, the feeders and some miscellaneous reactor components at the reactor face area. Depending on individual contracts, Retube/Refurbishment projects may also include the design and construction of a waste storage facility and transfer of the Retube/Refurbishment wastes to the facility.

Because of the neutron activation of materials within the core during normal operation, and the accumulation of radioactive deposits in the heat transport system, most of the Retube/Refurbishment wastes are radioactive (e.g. the fuel channel components and the feeders). Working with these radioactive wastes will challenge radiation protection and health physics procedures and would be hazardous to the safety and health of the workers unless appropriate prevention principles are applied and established safety work practices are used. In applying these principles and practices, proper management, training and properly assigned responsibilities will prepare workers to cope with these radiation hazards.

The amount of work to Retube/Refurbish a reactor is beyond the normal scope of the plant operation or outstage activities. Therefore, additional tooling, work procedures, and safety programs etc. are needed to conduct the work involved in refurbishment. As an integral part of AECL's Retube/Refurbishment projects, a specific radiation protection (RP) program has been developed for the projects. This RP program, driven by the As Low As Reasonably Achievable, social and economic factors taken into account (ALARA) principle, defines RP activities throughout the Refurbishment/Retube project to ensure that the workers, the public and the environment are well protected during the Retube/Refurbishment activities.

This RP program also ensures the Retube/Refurbishment projects will comply with CNSC and AECL radiation protection requirements, contractual obligation and client regulatory requirements. Therefore, the RP program interacts closely with every aspect of the Retube/Refurbishment projects. Figure 1 shows schematically the role of the RP program in AECL Retube/Refurbishment projects.

The following sections will
- identify the radiation sources for the entire duration of the Retube/Refurbishment project,
- discuss the major RP principles, and
- discuss how these RP principles are applied in each of the Retube/Refurbishment phases.

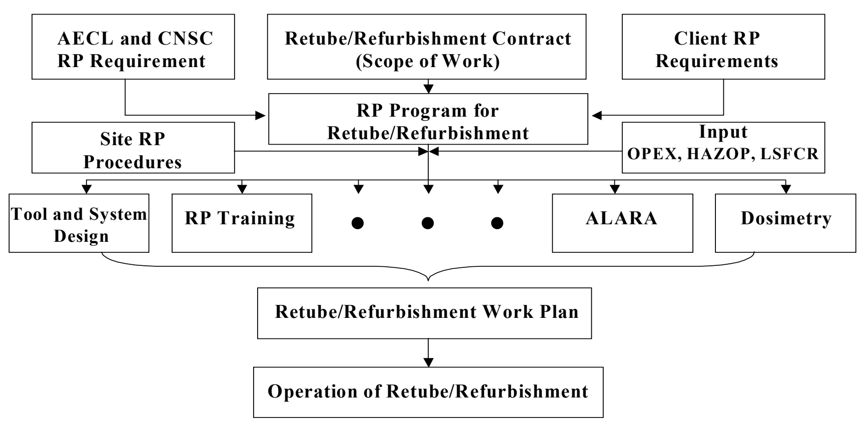

Figure 1 Radiation Protection Program in AECL Retube/Refurbishment Project

2 Radiation Sources

Radiation sources encountered during Retube/Refurbishment include fixed gamma sources, as well as contamination. The activation fixed gamma sources are those reactor components to be replaced during Retube/Refurbishment operation, such as, fuel channel (FC) and feeders[1], as well as the remaining reactor components, such as the calandria-side tube sheets, the end shields, and adjusters etc. Figure 2 shows a CANDU® 6 reactor assembly where various reactor components will be replaced during Retube/Refurbishment Operations.

Airborne and surface contamination hazards may arise from a release of particulates when removing the pressure tubes, calandria tubes, calandria tube inserts, feeder pipes, and garter springs during the retubing operations. In addition, tritium can be released from

- residual tritiated heavy water coolant remaining in the PHTS and auxiliary system volume after vacuum drying;
- residual tritiated heavy water coolant trapped in magnetite pores in inlet feeder pipes; and

  residual tritiated heavy water coolant remaining in pressure tubes

The radioactivity in the Retube/Refurbishment wastes varies widely, depending on the original location of the components. Because of the build up of radioactivity in the materials within the reactor core through their exposure to neutron flux during normal reactor operation, the replaced FC components are the most radioactive. Additionally, the accumulation of radioactive deposits from corrosion and fission products on the wetted surfaces will make components, such as the inlet feeder pipes that are located outside the region of high neutron flux, radioactively contaminated.

Table 1 lists the major radiation sources as a function of Retube/Refurbishment phases. Radiation source/environment varies as the Retube/Refurbishment project progresses, since radioactive components are continuously replaced, and other radiation sources (such as the calandria-side tube sheets) that are previously shielded by other radioactive components are exposed.

Table 2 lists the estimated background, transient and beam dose rates at various locations throughout the Retube/Refurbishment project. Note that the background dose rates drop slowly during the feeder removal phase (T1 – T6), and become small after the removal of end fittings[2]. Thus, from ALARA point of view, the faster the feeder removal phase is completed, the greater the saving on radiation dose expenditure will be. After feeder removal, the biggest concern from RP point of view is the high transient and beam (from an open channel) dose rates to be encountered during FC removal operation.

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[1] In addition to the FC components and feeders, there are other non-compactable and compactable wastes with relatively low level of radioactivity (mostly from deposit radioactive corrosion products) from the retubing campaign

[2] Note that the background dose rates after the removal of end fittings have already taken the RP measure (thumbtack shielding design for the Retube/Refurbishment projects) at the reactor face into consideration.

With the radiation sources identified and the strength estimated, RP activities will be planned and implemented throughout the projects, following the three RP principles to be discussed in the next section.

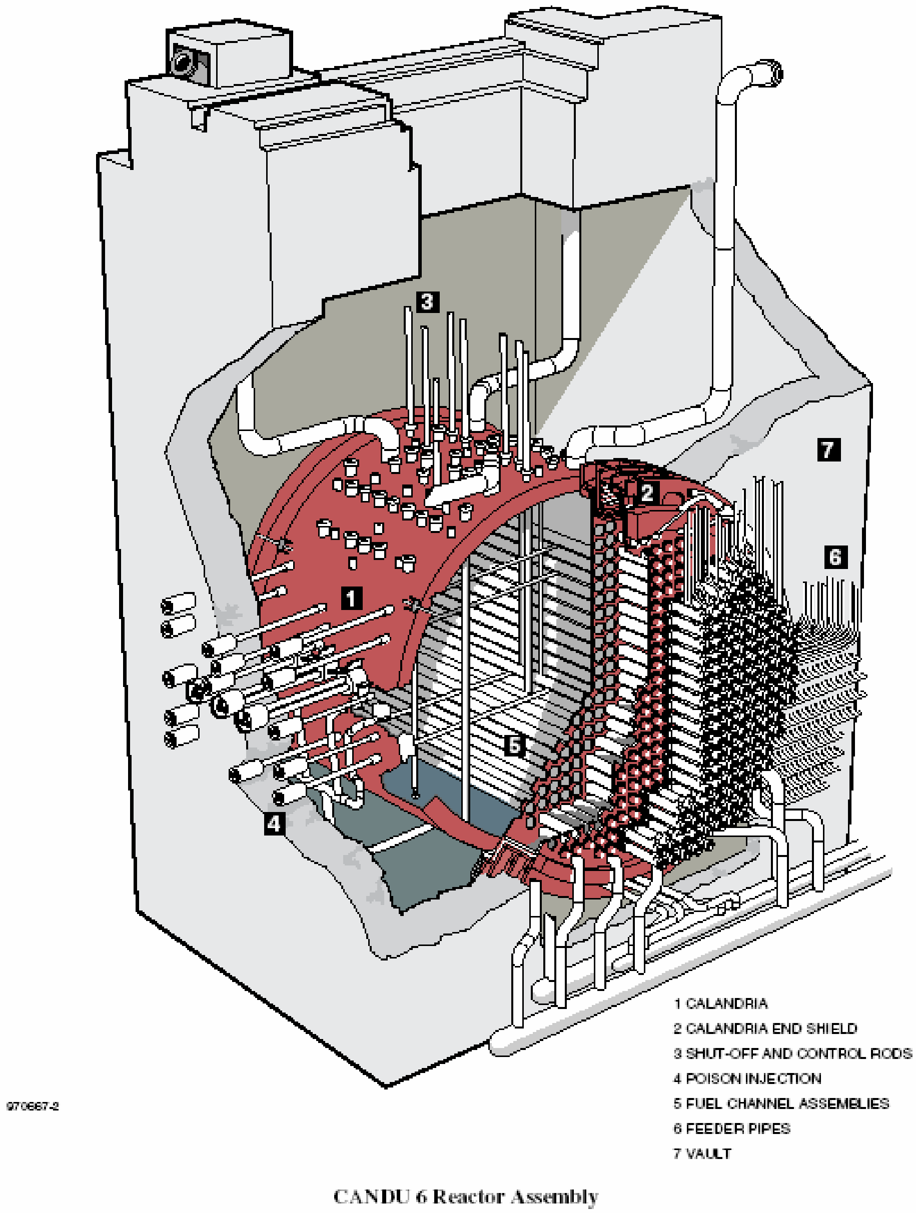

Figure 2 CANDU® 6 Reactor Assembly showing various components to be replaced during Retube/Refurbishment Projects

Table 1 Radiation Sources as a Function of Retube/refurbishment Phases

Retube/Refurbishment Phase		Radiation sources		
		Fixed Gamma Radiation	Contamination	Transient/Beam
T1	AECL vault preparation	All reactor components and feeders	^{3}H	No
T2	Feeder cabinet removal	All reactor components and feeders	^{3}H	No
T3	Feeder removal preparation activities	All reactor components and feeders	^{3}H	No
T4	Lower vertical feeder removal	All reactor components, feeders and end-fittings	Other airborne and surface contamination ^{3}H	No
T5	Lower horizontal feeder removal	All reactor components, feeders and end-fittings	Other airborne and surface contamination ^{3}H	No
T6	Upper feeder removal	All reactor components, feeders and end-fittings	Other airborne and surface contamination ^{3}H	No
T7	Pre-fuel channel removal operation	All reactor components, feeders and end-fittings	Other airborne and surface contamination ^{3}H	No
T8	End Fitting to Pressure Tube Separation and Removal	All reactor components and end-fittings	Other airborne and surface contamination ^{3}H	Yes
T9	Pressure Tube removal	All reactor components	Other airborne and surface contamination ^{3}H	Yes
T10	Release Calandria Tube Insert	All reactor components	Other airborne and surface contamination ^{3}H	Yes
T11	Removal Calandria Tube Insert	All reactor components	Other airborne and surface contamination ^{3}H	Yes
T12	Removal Calandria Tube	All reactor components	Other airborne and surface contamination ^{3}H	Yes
T13	Pre-installation inspections	Shielded reactor components	No	No
T14	Upper feeder installation	Shielded reactor components	No	No
T15	Calandria Tube Installation	Shielded reactor components	No	Yes
T16	Fuel channel installation	Shielded reactor components	No	Yes
T17	Lower feeder installation	Shielded reactor components	No	No
T18	New fuel loading	Shielded reactor components	No	Yes
T19	Feeder cabinet installation	Shielded reactor components	No	No
T20	AECL vault restoration	Shielded reactor components	No	No

Table 2 Dose Rates [mSv h^{-1}] at Various Locations throughout the Retube/Refurbishment Project

Phase	PHTS Headers	Fuelling Machine Bridge Top Mounted Platform	Fuel Channel Work Platform			Floor Mounted Platform	Vault Floor	Fuelling Machine Maintenance Area
	Background	background	Background	Beam*	Transient	Background	background	background
T1	1.01	0.76	0.48			0.25	0.14	0.044
T2	1.01	0.74	0.47			0.25	0.14	0.043
T3	0.97	0.74	0.47			0.25	0.14	0.043
T4	0.94	0.71	0.46			0.24	0.14	0.042
T5	0.89	0.57	0.40			0.23	0.13	0.040
T6	0.82	0.41	0.21			0.08	0.03	0.012
T7	0.05	0.02	0.08			0.07	0.02	0.005
T8	0.05	0.02	0.07	0.38	0.06	0.07	0.02	0.005
T9	0.02	0.02	0.02	0.38	1.05	0.02	0.02	0.005
T10	0.02	0.02	0.02	0.38		0.02	0.02	0.005
T11	0.02	0.02	0.02	0.38	0.11	0.02	0.02	0.005
T12	0.02	0.02	0.02	0.38	0.37	0.02	0.02	0.005
T13	0.02	0.02	0.02	0.38		0.02	0.02	0.005
T14	0.02	0.02	0.02			0.02	0.02	0.005
T15	0.02	0.02	0.02	0.38		0.02	0.02	0.005
T16	0.02	0.02	0.02	0.26		0.02	0.02	0.005
T17	0.02	0.02	0.02			0.02	0.02	0.005
T18	0.02	0.02	0.02	0.02		0.02	0.02	0.005
T19	0.02	0.02	0.02			0.02	0.02	0.005
T20	0.02	0.02	0.02			0.02	0.02	0.005

* These are dose rate outside the beam at locations where the workers are expected to be during the Retube operation.

3 Basic RP Principles

The following three RP principles are based on the recommendations of the International Commission on Radiological Protection (ICRP) [1]:

- **Principle of justifications**
  The benefits of working in a radiation environment must outweigh the drawbacks.

  Retube/Refurbishment of a CANDU® reactor provides a great economical saving over the construction of a new reactor.

- **Principle of optimisation** *(ALARA principle, As Low As Reasonably Achievable)*
  Radiation exposure caused by the use of radiation must be kept as low as reasonably achievable.

  The driving force and the primary principle of RP is ALARA. AECL has prepared an ALARA plan that provides optimisation guidelines for the project

- **Principle of limitation**
  Exposure of radiation workers and individuals of public must not exceed dose limits

  As an important RP activity, a series of dose rate targets has been defined throughout the project that will limit radiation exposure to workers

These RP principles, along with other safety programs (OPerating Experience (OPEX), Hazard analysis and human factor analysis) will be applied throughout the project.

4 RP in Retubing Tool and System Design

AECL Retube/Refurbishment project has divided the entire retube operation into a number of smaller jobs called retube series. In each of the retube series, AECL designers define the work location, prerequisites, and tools required, and estimate work duration and personnel requirement etc. Radiation protection in this design process is to provide radiation dose environment for all retube series so that the designers would optimize the operations to limit personnel exposure to the potential radiation hazards.

The project's RP program also requires that all retube tool design follow the ALARA tool design guide, and the designs are reviewed and approved by radiation physicist to ensure that RP has been adequately addressed. Table 3 shows the ALARA checklist the designers need to check during their tool design.

As an example of RP in the retube system design, at an early stage of the retube concept, the reactor core was to be de-fuelled, PHTS drained, flushed with light water and drained again. This concept created a series of steps to ensure that the end fittings and pressure tubes would be completely dry when they were shipped to the waste storage facility. An ALARA decision by the project was to undertake bulk drying of the heat transport system. As a result, one step involved withdrawal of the shield plug and vacuuming any residual water trapped in the bottle bore and swabbing water from the pressure tube sag followed by re-installation of the shield plug was eliminated, reducing radiation exposure to personnel for the project.

Table 3: ALARA Checklist for Tool Designer for Retube

		Yes	No
Maximize Distance from a Radioactive Source		Yes	No
1	Has alternative tool (e.g. remote) be considered that will reduce the radiation exposure?	☐	☐
	Resolution		
	Response		
Maximize Distance from a Radioactive Source		Yes	No
2	Is maximum distance provided between the serviceable components and the radiation source in the design of the tool?	☐	☐
	Resolution		
	Response		
Construction Material		Yes	No
3	Are surfaces smooth/or painted for easy decontamination?	☐	☐
	Resolution		
	Response		
Radiation Shielding		Yes	No
4	Is shielding placed between radiation source and personnel sufficient so that dose rates on contact with the tool and 1 m from the tool are below the dose targets?	☐	☐
	Resolution		
	Response		
Radiation Shielding		Yes	No
5	Are shields employed in the design of this tool to prevent streaming of radiation through the open channels?	☐	☐
	Resolution		
	Response		
Radiation Shielding During Transient		Yes	No
6	If the tool is going to be exposed in a transient dose environment, has the shielding calculation be performed to ensure the total dose received by the personnel will not exceed the dose limits?	☐	☐
	Resolution		
	Response		
Minimize Time in A Radiation Field		Yes	No
7	Has the tool been designed to facilitate maintenance or quick replacement?	☐	☐
	Resolution		
	Response		
Minimize Time in A Radiation Field		Yes	No
8	Does the equipment require modification or calibration prior to use? If so, can the maintenance, calibration and modification to the tool be done in a non-radiological controlled area?	☐	☐
	Resolution		
	Response		
Optimisation of Manpower		Yes	No

9	Have human factors been considered in the design of the tool, in terms of work efficiency and others?	☐	☐
	Resolution		
	Response		
Optimisation of Manpower		Yes	No
10	Has the design considered the work procedure (interface, parallel works etc.), so that the equipment will be used effectively?	☐	☐
	Resolution		
	Response		
Control of Loose Contamination		Yes	No
11	Does the tool design incorporate features that will minimize the like hood of the spread of loose contamination in the work area?	☐	☐
	Resolution		
	Response		

5 RP in Working Package Preparation

RP support of the working package preparation is to provide detailed radiation dose rate estimate in the area where each Retube/Refurbishment operation takes place. As an important input, along with the hazard analysis and human factor analysis, radiation environment analysis and a preliminary ALARA dose assessment for the retube series will allow the project to:

- Plan the works with proper operation as well as the site RP procedures
- Conduct necessary ALARA assessment for certain high dose expenditure work following the site ALARA program
- Develop project-specific RP procedures
- Establish the radiation monitoring requirement for each activity
- Determine RP assistant requirements

6 RP Training

RP training is a very important step to reduce radiation exposure to personnel. It is to ensure that the works will be performed according to procedures so that RP measures are properly followed. AECL retube training manual specifies:

- All retube workers will receive a basic RP training to a proper status in accordance with the site RP requirementsIn addition to the normal RP training, personnel directly involved in the field work of the retube project must be thoroughly trained in the operations that are necessary to complete their job. This will be an integrated training that takes into account of tool operation and RP procedures using a mock-up facility

7 RP for Retube/Refurbishment Operation

AECL Retube/Refurbishment team will work closely with the site RP staffs to make sure that the Retube/Refurbishment project integrates well into the site RP program.

This means that the Retube/Refurbishment operation will abide the site RP and ALARA procedures. In addition to follow the site procedures, AECL may also develop Retube/Refurbishment specific procedures, and define dose rate limits for Retube/Refurbishment transient operations.

The project realizes that some of the transient operations (replacement of fuel channel components) will create high radiation hazard. In order to limit personnel radiation exposure, the project has set a transient dose rate limit of 10 mSv/h in areas where workers could be present for the design purpose. This transient dose rate allows the development of a viable shield design needed to attenuate the radiation fields from the radioactive components withdrawn from the fuel channels.

The rationale of setting this transient dose rate limit is that, given the duration of a transient operation, the transient dose rate limit should be low enough so that the integrated dose would be small compared with the overall dose allowed, 20 mSv.

8 RP in Waste Transfer and Waste Storage

Large amount of radioactive wastes produced during Retube/Refurbishment will be packaged and transferred out of the reactor building to the waste storage facility for storage. To reduce radiation exposure during these operations, the project has set dose rate limits for the waste transfer flasks and for the waste storage facility.

For the replaced fuel channel components, because of the high level of radioactivity, the wastes will be transferred by lead flasks designed by AECL. The rest of the retube wastes will be packaged in commercially available steel or cardboard boxes.

For the lead flasks, the project sets the following dose rate targets:

1. On contact with the flask < 250μSv/h
2. At 1-metre from the surface of the flask < 25μSv/h

Depending on the particular retube/refurbishment project, the rest of the relatively low level of radioactive material may also be shielded during their transfer to the waste storage facility. But for now, the project has set the dose rate limit of the low-level waste as less than 2 mSv/h on contact. This is consistent with most of the CANDU® stations.

The dose limits for the transfer flasks are relatively lower than those used at CANDU® stations. This is conservative, and partially takes account of the reduction in allowable dose limit from 50 mSv/h to 20 m Sv/h since 1988.

The dose limits designed for the storage facility are

1. On contact with the structure < 25μSv/h
2. At 1-metre from the surface of the concrete < 2.5μSv/h

These dose rates are consistent with the dose rates used for the other waste storage facilities at CANDU® stations, which is to ensure that the occupancy outside the security fence around the waste storage facility does not receive an accumulated dose of 1 mSv per year, which is the regulatory dose limit for non Nuclear Energy Workers.

9 RP Data Management

The manpower necessary to complete the retubing work will be partially dictated by the radiation exposure of each individual. To that end a dose estimate for the entire project will be prepared and that estimate will be broken down by job series.

From that manpower estimate the necessary RP data management tools can be identified. The data management process will allow for a real-time estimate of workers dose as well as a historical query-able record. That information will be used for on-the-job work planning and ALARA assessments.

10 Summary

This paper describes RP aspect of AECL's Retube/Refurbishment projects, which is designed specifically for the Retube/Refurbishment of CANDU® reactors. The program complies with CNSC and AECL RP requirements, and follows the site RP procedures. The RP program follows the three RP principles, i.e. job justification, optimization (ALARA) and limitation on dose rate, and focuses on radiation protection initiatives from engineering design point of view. The program is to ensure a structured approach of RP for AECL's Retube/Refurbishment Projects.

11 Acknowledgement

Much of the work on radiation dose rate estimates in support of radiation protection measures for AECL's Retube/Refurbishment projects have been produced by the A. Rai, P. Smith, V. Aleyaseen, K. Tsang and R. Khaloo at AECL SP.

12 References

[1] International Commission on Radiological Protection, ICRP Publication 60, 1990 Recommendations of the International Commission on Radiological Protection: Pergamon Press, 1991.