Dosimetry Results for AECL Personnel Involved in Maintenance Activities at Off-shore CANDU Stations

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ABSTRACT

Atomic Energy of Canada Limited (AECL) is intermittently involved in maintenance work on domestic and off-shore CANDU nuclear power plants. Maintenance activities, such as fuel-channel replacement (FCR), small-scale spacer location and relocation (SLARETTE) and primary-side steam-generator tube cleaning, require work in high-radiation fields. This may lead to appreciable radiation doses. AECL staff experience has been that these radiation doses accrue mostly from external gamma fields, with a minor internal dose component from the uptake of tritiated water vapour. There are no significant uptakes of other radionuclides.

AECL practice for SLARETTE and FCR work at off-shore CANDU stations has been to equip AECL personnel with 1 set of thermoluminescent dosimeters (TLDs) and 1 direct-reading personal alarming dosimeter (PAD). These TLDs are read at the Chalk River Laboratories of AECL. In addition, off-shore site radiation protection personnel issue AECL personnel with a TLD. This TLD is subsequently read at the off-shore site. Consequently, there are often three independent measurements of dose from external fields for AECL personnel.

Internal dose assessments rely on off-shore radiation protection personnel. All off-shore CANDU stations use urine bioassay methods for tritiated water uptakes. Most off-shore CANDU sites also have lung or whole-body gamma spectrometry capabilities or both, which, if necessary, can be used to assess doses from uptakes of gamma-emitting airborne contaminants (e.g., from $^{60}$Co, $^{95}$Zr, $^{95}$Nb, etc.).

This paper discusses some internal and external dosimetry data for AECL personnel involved in recent FCR and SLARETTE work at off-shore CANDU stations. The data show that the whole-body dose contribution from uptake of tritiated heavy water is small. The data also show that three independent external dosimetry systems give dose results that are in relatively close agreement. Such information is invaluable in promoting confidence in the various dosimetry systems used under field conditions and allows Sheridan Park Health Physics staff to address any spurious measurements. The dosimetry data are also useful in planning future maintenance work.

## INTRODUCTION:

Atomic Energy of Canada's Sheridan Park site and its affiliated sites, labelled here as AECL-SP, routinely monitors its atomic radiation workers (about 150 of its ~900 employees) for radiation exposures. These monitored employees are involved in a wide range of activities ranging from periodic reactor-site visits to high- radiation-field maintenance work. They typically work at reactor sites in Canada (i.e., Pickering, Darlington, Bruce, Point Lepreau, Gentilly-2) and at off-shore CANDU sites in Argentina, Korea and Romania. However, on occasion, work has been done in Slovenia and Russia.

Of the ~150 AECL-SP employees monitored for occupational radiation exposures, about one third are involved in high-radiation-field work, such as fuel-channel replacement (FCR), small-scale spacer location and relocation (SLARETTE) and steam-generator maintenance. The number of employees involved in high-radiation-field work varies from year to year, depending on the maintenance work schedule. Consequently, radiation exposures also exhibit annual variations. It is also common for the same group of employees to perform maintenance tasks at domestic and off-shore sites in the same year. Consequently, a small group of employees receive a disproportionate amount of the collective radiation dose.

Figures 1 and 2 show the distributions of whole-body dose for AECL-SP employees for 1995 and 1996 respectively. Most of the monitored employees are in radiation fields for short periods of time and receive little or no occupational exposures. Typically, 90% of the monitored employees receive about 10 to 20% of the collective dose; or conversely, 10% of the employees receive 80 to 90% of the collective dose. Therefore, it is appropriate that attention and effort be focused on radiation exposures to employees involved in high-radiation-field maintenance work and receiving most of the annual collective dose.

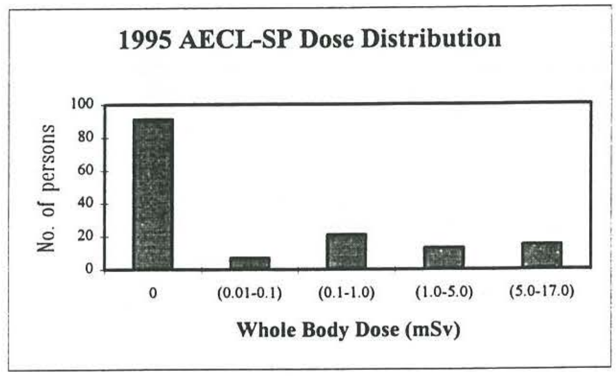


Figure 1: 1995 AECL-SP Dose Distribution

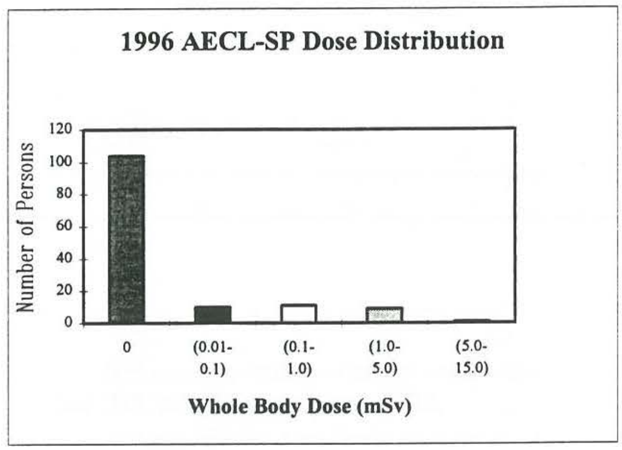


Figure 2: 1996 AECL-SP Dose Distribution

At domestic CANDU sites, AECL employees involved in radiation work are monitored with thermoluminescent dosimeters (TLDs) and personal alarming dosimeters (PADs) for external exposures, while urine bioassays and whole-body counting are used for internal exposures. Radiation doses from Canadian sites are reported to AECL on a monthly and quarterly basis by site staff, and are consolidated in employees' personal dose records.

Radiation protection practice at off-shore sites sometimes differs from the radiation protection practice employed at domestic CANDU stations. The adequacy of radiation protection and monitoring offered by off-shore sites has been questioned by AECL staff. This, together with the remoteness of the work location, has meant that for high-radiation-field work at off-shore sites, employees are routinely issued TLDs and a PAD by AECL-SP Health Physics staff. Off-shore site radiation protection staff also issue TLDs to AECL personnel. Thus there are usually three independent measurements of external dose. Internal exposures are monitored by urine bioassay and, if necessary, by whole-body or lung counting at a site. Since the biological half-life of tritium is about 10 d, it is impractical to perform these bioassays on staff on their return to Sheridan Park. The rest of this paper will discuss the results of some of these dosimetric measurements for work at off-shore CANDU sites and the implications for future high-radiation-field radiation work.

## DOSIMETRY USED FOR OFF-SHORE WORK

Employees involved in off-shore high-radiation-field maintenance work are each issued, from AECL-SP, 2 TLD badges: one badge is used as a control and the other badge is used as a field dosimeter. These dosimeters are kept together during travel to the site; they are kept separately when radiation work is to be performed. Then, the control TLD badge is placed in a background radiation field environment (such as a hotel room) and the field TLD badge is taken into the high-radiation field where work is to be done. On completion of work, the control and field TLD badges are again kept together until they re returned to AECL-SP, and from there to AECL-CRL (Chalk River Laboratories) for reading. Control readings are subtracted from field readings to yield the accumulated dose. By doing so, radiation exposures obtained from cosmic rays during the flight and from other background sources are excluded from the occupational dose records.

The presence of a large number of control dosimeters for maintenance projects enables easy troubleshooting of anomalous readings and flexibility in the assignment of staff. For example, background correction is person-dependent, rather than constant for the whole group when only one control TLD is used. Therefore, employees can have varying lengths of stay for the project without affecting dosimetry. In addition, improper handling of control and field TLD badges can sometimes be identified and with multiple control TLD badges, the readings could subsequently be corrected/discounted.

Each TLD badge contains 2 TLD chips, some activation foils, sulphur tablets and CR-39 plastic. The activation foils and sulphur tablets can detect high neutron doses from criticality events. The CR-39 plastic detects thermal neutron fields and neutron fields of energy greater than about 100 keV. The presence of 2 TLD chips in each badge enables the whole-body dose and skin dose to be estimated from the thick and thin TLD chips respectively. The CR-39 track etch dosimeters are read only when neutron exposures are suspected based on excessively high ratio of thick to thin TLD chip measurements.

AECL-SP staff also issue maintenance workers with PADs for dose-control purposes. Currently, ALNOR 101-R units are used. These units can display cumulative external whole-body dose and dose rate, and have alarm set points for cumulative dose and dose rate. Although, the TLD badges are the official dosimeters of record, they are unable to provide any real-time dose measurements. PADs accomplish this task and are invaluable for dose control, work planning and prevention of overexposures from unexpected radiation fields.

Off-shore site staff also routinely provide AECL-SP staff with TLDs. These TLDs are read by off-shore site staff, and the results are communicated to AECL-SP Health Physics staff.

## MAINTENANCE ACTIVITIES

AECL-SP staff are involved in periodic inspections of reactor components, fuel-channel replacements (FCR), garter-spring repositioning using SLARETTE, and primary-side steam-generator-tube cleaning (SGTC) at CANDU reactors.

Fuel-channel replacement activities involve the removal and replacement of a fuel channel. AECL participated in selective FCRs at KANUPP in 1993, Wolsong Unit 1 in 1994, and Embalse in 1995. However, since then, there have been no requests from off-shore CANDU stations for FCRs. At KANUPP, AECL utilized KANUPP staff for most of the work performed in high-radiation fields and were themselves involved more in a supervisory and training capacity. At Embalse in 1995, a situation similar to that at KANUPP prevailed. However, at Wolsong in 1994, AECL staff were more involved in most of the high-radiation-field work near the reactor face with assistance from site staff. There were also some unexpected problems during this maintenance work.

Consequently, radiation exposures were higher at Wolsong.

AECL-SP staff have been involved in SLARETTE operations annually for the past 3 years at Wolsong, Gentilly-2 and Embalse. It is expected that SLARETTE work (garter-spring inspections and relocations) will continue at these sites annually or once every 2 years until these reactors are retubed and garter springs are replaced with the improved spacer design.

AECL-SP staff have also been involved in primary-side steam-generator-tube cleaning at Gentilly-2 and Point Lepreau. This is high-radiation- field work that is due to corrosion-product activity in the primary side. However, remote tooling is being increasingly applied, leading to reductions in radiation exposures. Other maintenance work periodically undertaken includes steam-generator divider-plate repairs and feeder-pipe repair. However, these are expected to be infrequent maintenance activities.

**DOSIMETRY DATA**

Data for AECL-SP employees who participated in the following selected projects at off-shore CANDU stations will be discussed.

1. the 1993 KANUPP Fuel Channel Replacement Project
2. the 1994 Wolsong Unit 1 Fuel Channel Replacement Project
3. the 1995 Wolsong SLARETTE project.

This cross section of data will be presented because it is fairly representative of recent experiences at off-shore sites.

**THE 1993 KANUPP FUEL CHANNEL REPLACEMENT**

Fuel-channel replacement involves removal of the pressure tube and end-fitting. This procedure is manpower intensive, requiring cutting and welding operations at the reactor face. The major hazard expected is from external gamma radiation principally from the pressure tubes due to Zr-95/Nb-95 activation products. Further away from the face, general gamma fields are due to corrosion-product activity in the feeders (largely Co-60) and direct gamma radiation from the face. In addition, there is tritiated water vapour in the atmosphere. Approximately 10 AECL employees were involved in this project. This was composed of two managers, two team leaders and 6 technologists and technicians. AECL's role, while being supervisory in nature, did involve work in the reactor vault.

Whole-body doses (obtained with film badges) and internal doses from tritium, (determined by urine bioassay), were reported to AECL-SP Health Physics staff by KANUPP staff.

These AECL employees also had TLD badges issued from AECL-CRL. No results from direct-reading PADs were available (these units were acquired by AECL-SP in 1995).

Figure 3 presents the comparison of external whole-body doses determined by KANUPP staff and external whole-body and skin doses determined by AECL-CRL TLDs. Figure 4 presents the internal doses (from tritium) and the reported total whole-body dose (internal + external and from tritium).

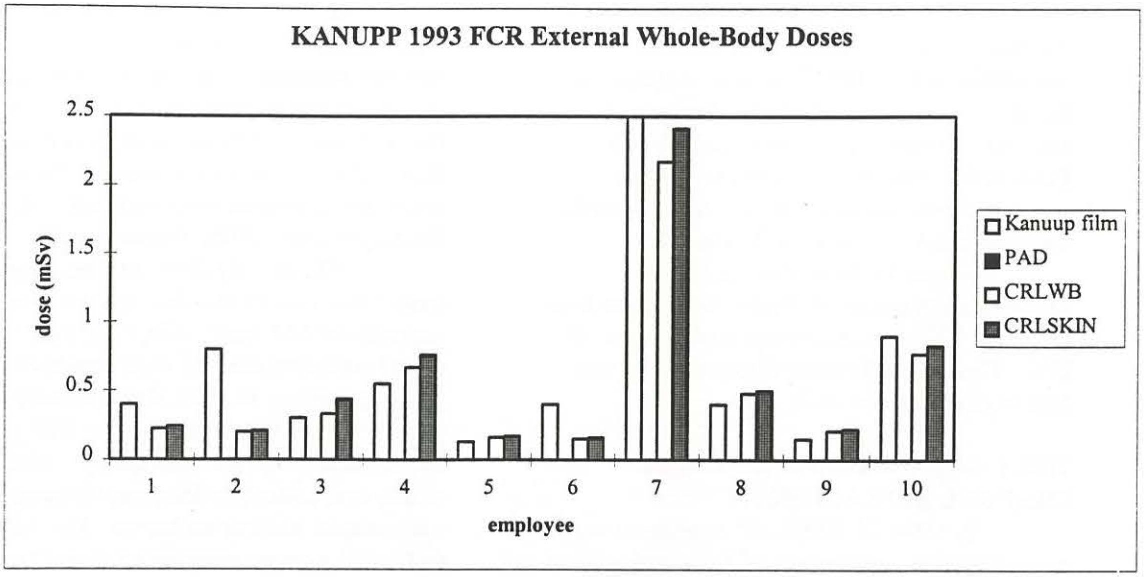


Figure 3: KANUPP 1993 FCR External Whole-Body Doses

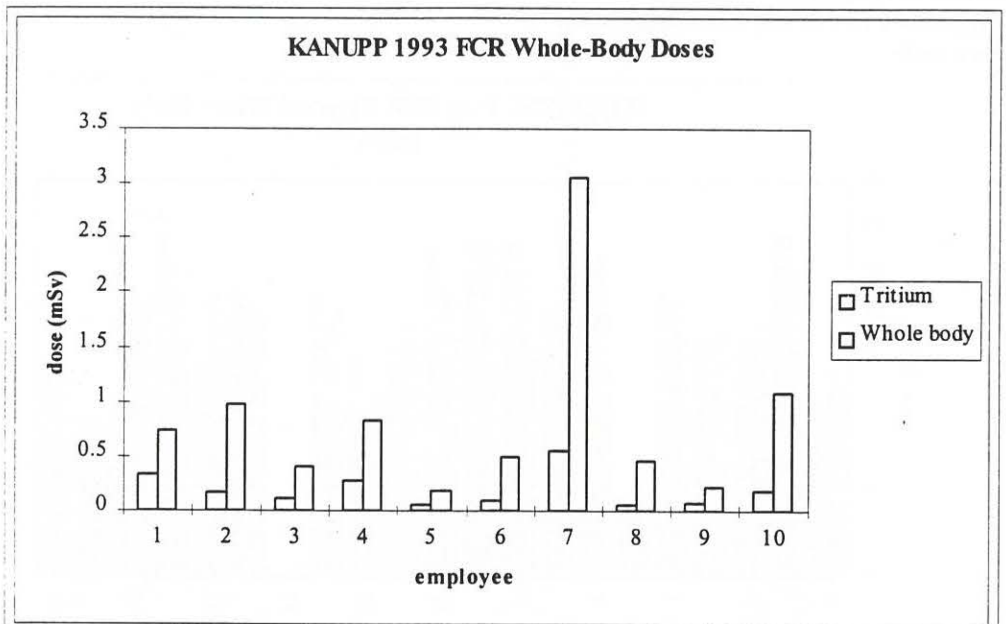


Figure 4: Tritium Contribution to Total Whole Body Dose

Figure 3 shows that most of the KANUPP-calculated doses are within 50% of the AECL-CRL TLD measurements. However, there are cases where the discrepancy is as high as 75%. Two independent dosimetry systems measuring small exposures (<5mSv) in a field setting, with the detectors at different locations on the body may be exposed in different exposure geometries. Also, poor counting statistics may contribute to variability in readings . Consequently, the variations between dosimetry systems can be large. However, one may expect a 50% agreement from good dosimetry systems, in broad-beam geometries and with proper use and handling of dosimeters.

Further investigations were conducted into what were regarded as anomalous readings. In one case, where the discrepancy was 75%, the individual admitted to not having worn his AECL-CRL dosimeter for a vault entry. For the other anomalous reading, no specific explanation was found. However, it should be noted that only one control TLD badge was used, and employees did not return their field TLDs at the same time. It is felt that closer agreement between readings should be possible with increased care in using TLDs.

Figure 4 reveals that the tritium contribution to the whole-body-dose ranges from 13 % to 45 %, with an average contribution of 25%. This is usually what is expected for this type of maintenance work.

## THE 1994 WOLSONG UNIT 1 FUEL CHANNEL REPLACEMENT

In 1994, 21 AECL-SP employees were involved in the replacement of 3 fuel channels at Wolsong Unit 1. This team was composed of 1 manager, 2 team leaders and 18 technologists, technicians and engineers. The project took approximately 1 month and required 2 around-the-clock shifts.

Employees were badged with AECL-CRL TLDs, PADs and Wolsong-site TLDs. Internal dosimetry was done by Wolsong staff. AECL-SP Health Physics were sent records of the Wolsong TLD measurements and the tritium doses. As well, some raw data of tritium-in-urine concentrations were supplied to AECL-SP Health Physics staff by Wolsong staff.

Whole-body doses for this project ranged from 0.1 to 16 mSv, with an average exposure of 10.6 mSv. AECL-SP staff received a total collective dose of 0.22 person-Sv. At the Wolsong station, in 1994, the reported total collective dose for the station was 2.80 person-Sv. Of this, 30% was from tritium. Also, 70% of this total collective dose was obtained during maintenance work at shutdown. The AECL-SP staff of 21 persons contributed slightly over 11% of the 1994 total station shutdown collective dose of 1.95 person-Sv, in an exposure period of about 1 month.

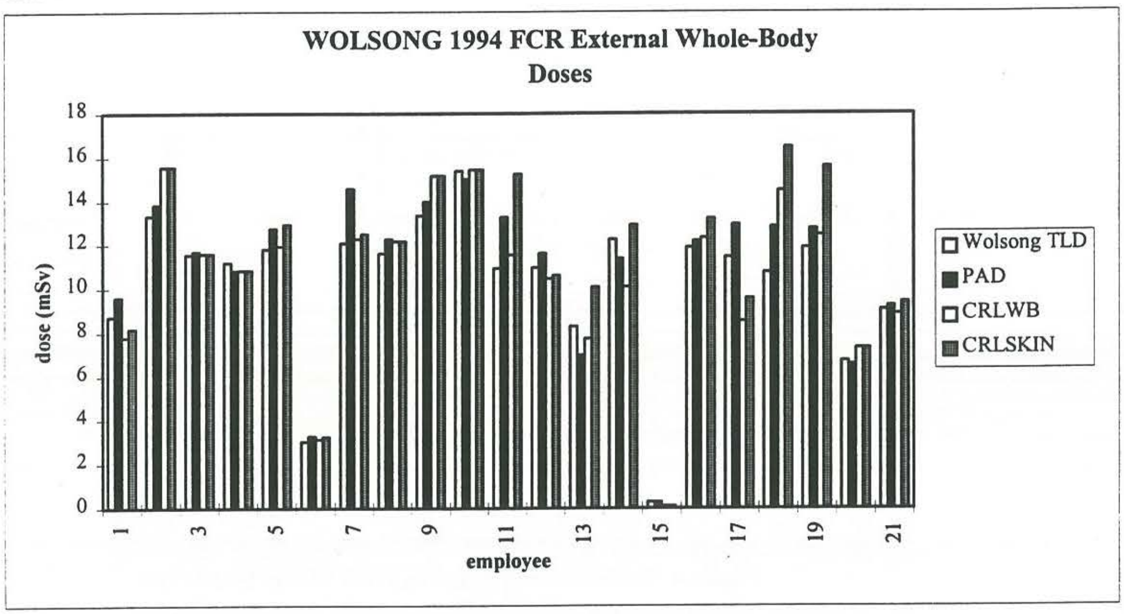


Figure 5: WOLSONG Unit 1 1994 FCR Doses

| | % difference | | |
|---|---|---|---|
| Employee# | W1-CRL | W1-PAD | CRL-PAD |
| 1 | 10.77 | 18.85 | 7.74 |
| 2 | 16.89 | 12.58 | 1.98 |
| 3 | 0.43 | 0.77 | 3.55 |
| 4 | 3.05 | 0.09 | 6.73 |
| 5 | 1.02 | 6.21 | 6.35 |
| 6 | 2.98 | 4.60 | 5.50 |
| 7 | 1.66 | 15.84 | 17.20 |
| 8 | 4.82 | 0.65 | 2.42 |
| 9 | 13.64 | 8.44 | 2.19 |
| 10 | 0.26 | 2.73 | 5.36 |
| 11 | 5.58 | 13.10 | 19.86 |
| 12 | 4.56 | 9.91 | 4.59 |
| 13 | 6.75 | 10.89 | 16.61 |
| 14 | 17.57 | 11.18 | 9.77 |
| 15 | 66.67 | 66.67 | 0.00 |
| 16 | 3.71 | 1.23 | 1.08 |
| 17 | 25.35 | 33.95 | 10.42 |
| 18 | 34.79 | 12.85 | 16.52 |
| 19 | 4.72 | 2.43 | 6.17 |
| 20 | 8.61 | 11.76 | 7.09 |
| 21 | 2.09 | 3.90 | 0.32 |
| Average | 11.23 | 11.84 | 7.21 |

Table 1: Percent Difference between External Dosimetry Readings for Wolsong 1 FCR in Figure 5

Figure 5 presents the intercomparison of PAD readings, external whole-body doses determined by Wolsong 1 TLDs, and external whole-body and skin doses determined from AECL-CRL TLDs. There is remarkable agreement among these three independent measurements of external dose. The percent differences between the three sets of measurements are given in Table 1. In general, the differences range from 0 to 34%, the average being less than 12%. Note that there is a discrepancy of 67% for employee 15. The doses corresponding to this discrepancy are of the order of 0.1 mSv. This is close to the lower level of detection of most dosimetry systems.

Provided the dosimeters are handled properly, AECL-CRL dosimetry services claim that the accuracy of their TLD system is within 20% at these dose levels. The agreement of 3 independent dosimetry systems also seems to be well within these levels.

Tritium doses compared with their respective total whole-body doses are given in Figure 6.

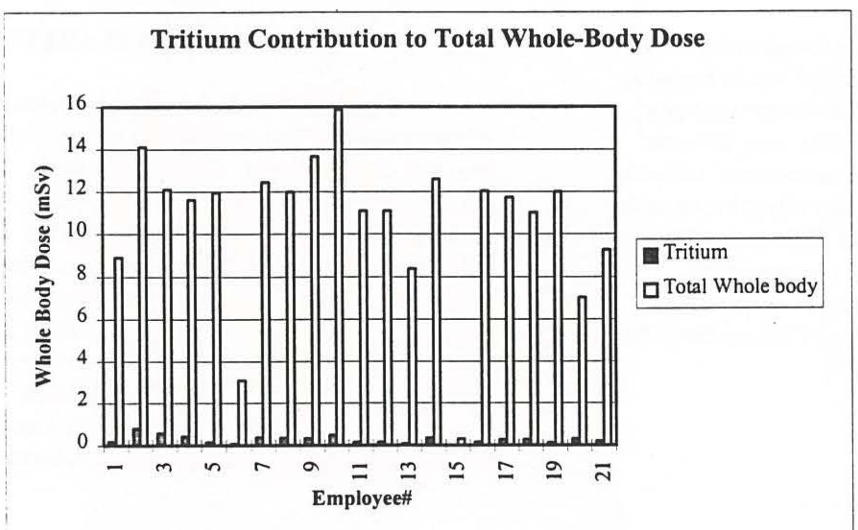


Figure 6: Tritium Contribution to the Total Whole-Body Dose for 1994 Wolsong Unit 1 FCR

For this FCR project, the tritium contribution to the total whole-body dose ranges from 0 to 6%. This is very small in relative terms because staff were in the proximity of very high external radiation fields from the removed fuel channel. Consequently, the external doses were disproportionately high.

AECL-SP Health Physics staff were also given measurements of tritium in urine concentrations. Consequently, internal dose estimates based on these data were made and compared with internal tritium dose estimates from Wolsong 1. The comparison is shown in Figure 7.

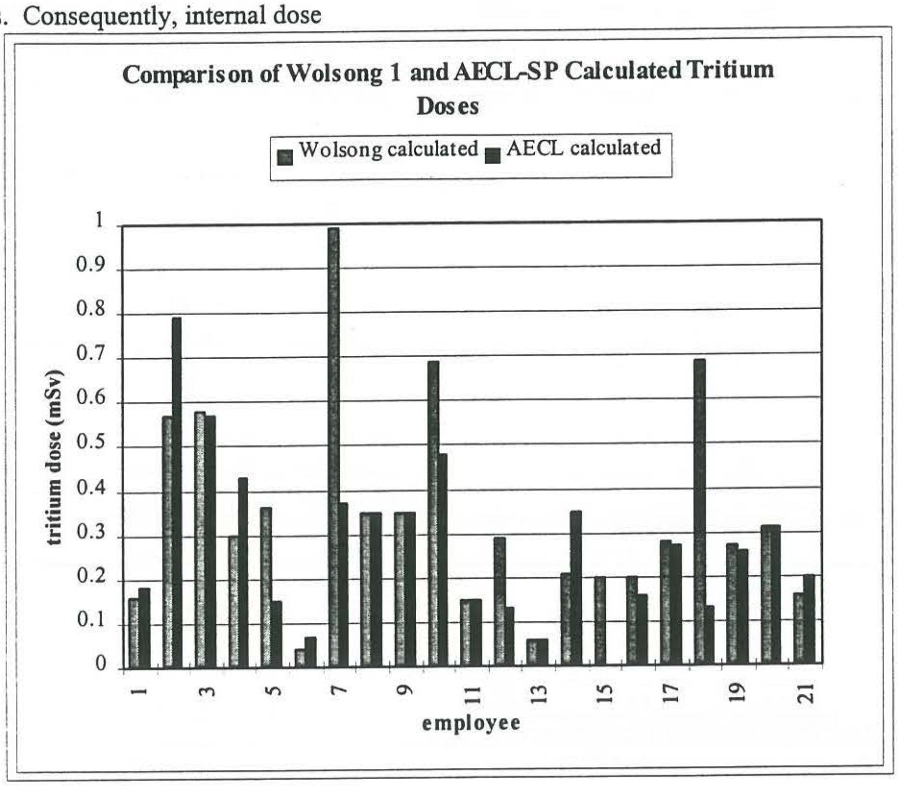


Figure 7: Comparison of Wolsong Unit 1 and AECL-SP Calculated Tritium Doses for 1994 FCR

The AECL-SP tritium calculations were done according to the Health Canada Bioassay Guideline 2- Guidelines for Tritium Bioassay, with the assumption that there were no acute intakes (i.e., intakes were spread over 1 month). There is generally good agreement between the methods, with an average difference of the order of 30%. Tritium-in-urine concentrations supplied to AECL were not as frequent as measurements taken at site. Consequently, the differences are as expected.

## THE 1995 WOLSONG UNIT 1 SLARETTE

SLARETTE involves the repositioning of garter springs that separate the pressure tube from the calandria tube. Usually this work involves 2 workers at the reactor face for latching and unlatching operations, and two others on the other side of the fuelling-machine bridge. There are usually one or two operators outside the reactor vault remotely operating the tool once it is set up and aligned. The general hazards expected are from airborne tritiated water vapour and external gamma fields from the fuel channels and from the feeder cabinets.

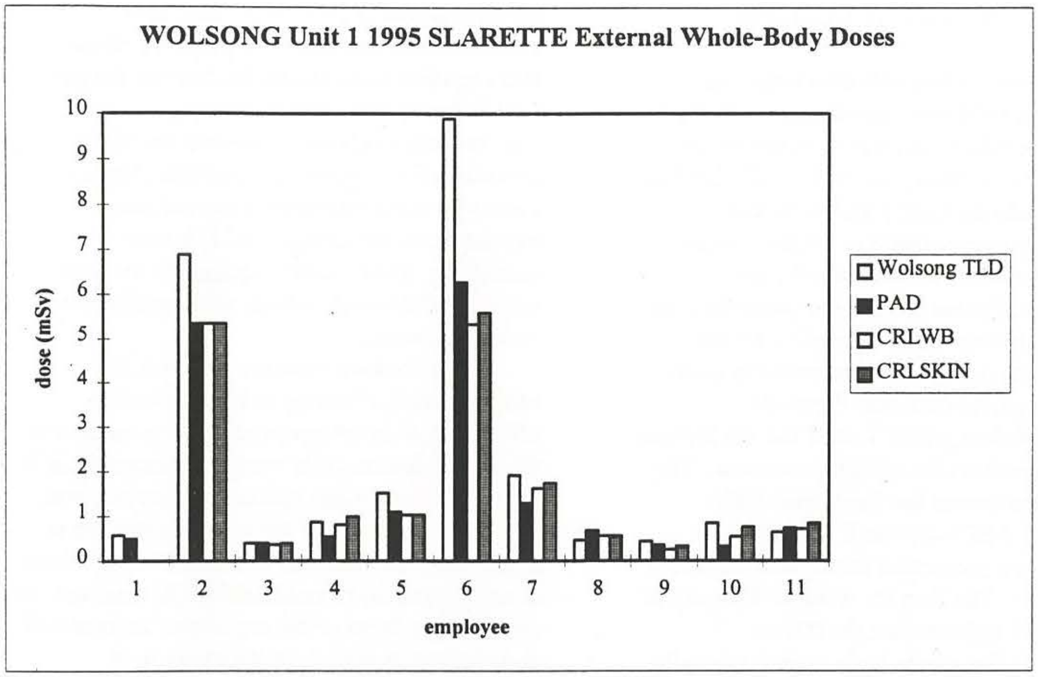


Figure 8: Wolsong Unit 1 1995 SLARETTE External Whole-Body Doses

Eleven AECL-SP staff, consisting of 2 team leaders and 9 technicans, technologists and engineers made up this team. Each AECL-SP employee had AECL-CRL TLDs, AECL-SP PADs and Wolsong Unit 1 TLDs. A comparison of the external whole-body doses is given in Figure 8.

The collective dose for this project was 0.03 person-Sv, with individual doses ranging from 0.5 mSv to 10 mSv. As can be seen, 2 employees received 5 mSv or more, the other AECL-SP staff averaged <1 mSv. The 2 employees receiving higher exposures were involved in latching–unlatching and tool-positioning operations. A large part of the high-field work on this project was undertaken by Wolsong or subcontracted staff, hence the overall small collective dose. There is good agreement between the 3 different external whole-body dose measurements. Usually discrepancies are of the order of 30% or less. When large discrepancies exist (employee 2 and 6), doses from Wolsong Unit 1 TLDs are higher. Some employees got slight external contamination on this project, and it is postulated that there were probably hot particles on the Wolsong dosimeter. However, no conclusive explanation was found.

Figure 9 shows the tritium contribution to the total whole-body dose. The average tritium contribution to the total whole-body dose is 7% and ranges from 0 to 22%. The tritium doses range from 0 to 1.3 mSv.

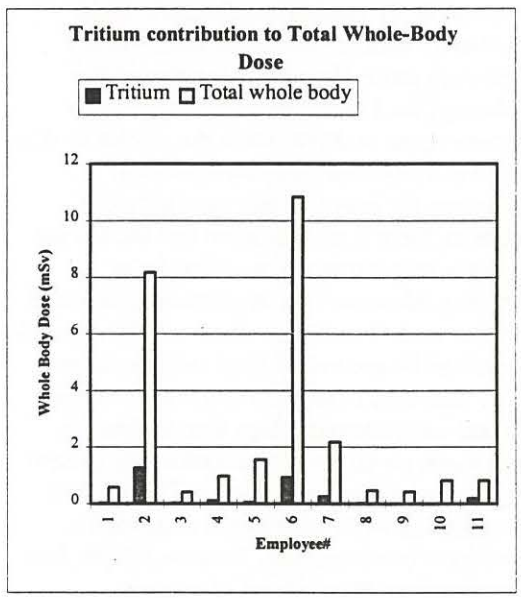


Figure 9: Tritium Contribution to the Total Whole-Body Dose for SLARETTE at Wolsong Unit 1 in 1995

## DISCUSSION AND CONCLUSIONS

The use of multiple dosimeters for high-radiation-field work at off-shore CANDU stations has provided conclusive evidence that all 3 dosimetry systems, i.e., PADs, AECL-CRL TLDs and Wolsong Unit 1 TLDs, do not systematically overestimate or underestimate radiation exposures. It also provides an assurance that if these devices are properly used and handled, the accuracy offered by all the systems is quite good. The agreement is quite impressive for field data (see Figure 5).

At Wolsong Unit 1, staff use the Korean ice bottle respirators for tritium protection. The efficacy of this device has been repeatedly questioned by AECL-SP staff. However, it claims to have a protection factor of at least 2, if properly used. The data for work at Wolsong in 1994 and 1995 indicate that the tritium contribution to the whole-body dose is typically within 20% of the total whole-body dose. This is consistent with data for Gentilly-2 and Point Lepreau reported in the CANDU station newsletter 96-03 (Reference 1). It is also consistent with detailed data given in G2-RT-95-51 rev.0 for Gentilly-2 (Reference 2), where the contribution of tritium to the total whole-body dose is typically less than 20%. However, because Point Lepreau operates with a very low dewpoint in the reactor building, it is often possible to work in the reactor vault without respiratory protection. It is also known that Wolsong Unit 1 can have high tritium-in-air concentrations at shutdown in the reactor vault (a few (2 to 3) derived air concentrations). Consequently, based on this circumstantial evidence, there is no indication that the Korean ice bottle respirators are not effective at providing adequate tritium protection, provided they are used as intended. However, this should be verified by controlled field and laboratory trials. Site staff have also been monitored for internal contamination other than tritium. In most cases, no other contamination was present. In a few cases, trace amounts of $^{95}Zr$ and $^{95}Nb$ (contributing <0.01 mSv of the individual's dose) have been detected. Because of their low concentrations, they are not of concern.

The contribution to the total whole-body dose for AECL-SP staff during maintenance work is dominated by external gamma fields. Following the as-low-as-reasonably-achievable (ALARA) principle, social and economic factors taken into consideration, AECL-SP employs the philosophy that radiation work should be done by the person who is best qualified to do it while minimizing total radiation exposures. Hence, the higher exposures for employees 2 and 6 as shown in Figure 9, while still having overall low exposures for the group. AECL is now employing more robotic equipment for high-radiation-field work, which will contribute to lower exposures.

Additional data are required for radiation work planning to become a more effective tool in optimizing radiation exposures for high-radiation-field work. For example, it is important to correlate radiation exposures with specific operations. If the work undertaken is correlated with radiation doses, and calculations or measurements of radiation fields, then one can assess where most of the exposures are received and investigate how to optimize work to minimize exposures. Such an optimization has not been comprehensively and systematically done. Such a task may offer some improvement in AECL-SP exposures. However, in the long term, if significant gains are to be made in reducing doses during maintenance work, then the sources of these external fields must be identified and addressed. AECL-SP is also working towards compliance with the reduced dose limits given in ICRP Publication 60 (Reference 3) for occupational exposures. ICRP-60 specifies that the effective dose should be less than 100 mSv in 5 a, with no year to exceed 50 mSv. Existing radiation work practices at AECL-SP currently demonstrate and ensure that radiation exposures are well within this dose limit.

**Acknowledgments:** Discussions and review from C.R. Boss and B.E. Heinmiller are appreciated.

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