# ALARA IMPLEMENTATION THROUGHOUT PROJECT LIFE CYCLE

Michael J. Haynes
Ontario Hydro
1549 Victoria Street East
Whitby, Ontario, Canada

## ABSTRACT

A strength of radiation protection programs generally has been endorsement and application of the ALARA principle. In Ontario Hydro, which currently operates 20 commercial size nuclear units, great strides have been made in the last three decades in reducing occupational radiation exposure per unit of electricity generated. This paper will discuss specific applications of elements of the overall ALARA program which have most contributed to dose reduction as the nuclear program has expanded. This includes such things as management commitment, ALARA application in the design phase and major rehabilitation work, the benefits of the self protection concept, a specific example of elimination (or reduction) of the source term and the importance of dose targets. Finally, it is concluded that the major opportunities for further improvements may lie in the area of information management.

## INTRODUCTION

**[slide 1]** Ontario Hydro has been operating nuclear power stations using reactors of the CANDU design since 1962 with the startup of the 22 MWe Nuclear Power Demonstration (NPD) station near Deep River, Ontario. This was followed by the startup of Douglas Point Generating Station, a larger scale prototype station (208 MWe) and the first nuclear facility to be built on the present Bruce site in 1967. Both of these stations are now shut down (1987 and 1985 respectively). Today, Ontario Hydro operates 20 commercial sized units with a total installed capacity of over 14,400 MWe, roughly half of Ontario's total electrical capacity **[slide 2]**. As nuclear units are normally operated as base load stations, total delivered energy from nuclear generation is currently on the order of 60%. These units are located at three geographical sites known as Pickering (8 x 515 MWe), Bruce (8 x 850 MWe) and Darlington (4 x 880 MWe). Pickering in turn consists of two stations (albeit under one roof), Pickering A, which came into service between 1971 and 1973, and Pickering B, which came into service between 1983 and 1986. There are two four unit stations on the Bruce site known as Bruce A and Bruce B which came into service between 1977 and 1979 and between 1984 and 1987 respectively. Darlington is a four unit station which came into service between 1990 and 1993.

A strong commitment to the management of radiation protection has been an essential feature of our nuclear program from the beginning. Corporate policy in radiation protection included a specific commitment to minimize and avoid unnecessary radiation exposure as far back as 1962[1].

The cost/benefit ratio of collective dose to energy produced has improved dramatically over the last three decades at Ontario Hydro stations **[slide 3]**. This is perhaps best illustrated by comparing total dose consumption in 1970, about 1585 person rem for 240 MWe installed capacity with total dose consumption in 1993, 1307 person rem for 14400 MWe capacity. So how has this been achieved? Clearly there are many factors but among the more important are: **[slide 4]**

* management commitment/corporate policy

* integration of operating experience with design of new facilities and rehabilitation of existing ones

* elimination of radioactive sources where possible

* training of personnel/self protection

* radioactive work planning

* use of protective equipment

* decontamination

* use of goals and dose targets

This paper will discuss a number of specific applications of some of these factors to Ontario Hydro's overall efforts at dose reduction and control.

## HISTORICAL DOSE PERFORMANCE

A brief orientation to CANDU design is necessary before discussing ALARA application. Some of the major differences and essential features relative to a light water PWR or BWR include: pressure tube design, the use of natural uranium fuel, independent coolant (Heat Transport) and Moderator Systems both using heavy water and on power refuelling. The basic circuit is illustrated in **Figure 1**.

Collective dose from the operation of Ontario Hydro reactors for the period 1963 to 1993 is shown in **Figure 2**. Note that a significant component of the total is a result of internal exposure. This occurs from exposure to tritium oxide normally in the form of tritiated water vapour as a result of leakage from the Heat Transport, Moderator and auxiliary systems. Tritium is produced in large quantities in the core of CANDU reactors as a result of neutron activation of deuterium in heavy water. In general, there has been a downward trend in collective dose over a long period of time followed by a levelling off at about 1300-1500 person rem/a despite significant increases in nuclear generation and major maintenance activities in the last few years. Our collective dose target for 1994 has been set at 1250 person rem.

Average individual doses have also decreased over time levelling off in recent years at just over 200 mrem per exposed worker **[Figure 3]**. This is in fact an established target of Ontario Hydro Nuclear policy, ie 200 mrem per exposed worker. The most highly exposed work group within our operating personnel for routine operations are the mechanical maintainers. Typical average doses for that group are about 300 mrem/a.

## MANAGEMENT COMMITMENT

Perhaps the most important and fundamental element of any corporate ALARA program is **management commitment**. This requires that senior management understand the ALARA concept, believe in it and actively support it in managing the business. In Ontario Hydro, the management of radiation protection has been governed by a set of internally generated Radiation Protection Regulations since 1962. These documents apply to all nuclear facilities in the corporation, to all phases of their life cycle and are authorized by our regulators, the Atomic Energy Control Board. Compliance with the Radiation Protection Regulations is a standard condition of each nuclear station's operating licence. **[slide 5]**

The present day Radiation Protection Regulations are prefaced by a set of RP Policies and Principles[2] including the following commitment to:

*Limit detrimental stochastic health effects occurring in employees or members of the public to levels as low as reasonably achievable, social and economic factors being taken into account (ALARA).*

This commitment is very real and is a primary driving force for many of the subsidiary RP programs in the design and operation of our plants. A tangible example of this commitment is the inclusion of collective dose targets for Ontario Hydro Nuclear as a whole and for individual stations into the performance contracts of nuclear executives. In short, *what gets measured gets done.*

## ALARA IN DESIGN AND REHABILITATION

### Design

Ontario Hydro recognized very early in its nuclear lifetime based on experience at the 208 MWe station known as Douglas Point that significant changes were required in the design of new stations to control radiation exposure. Specifically, it became obvious early on (late 1960's) that one of the major causes of high dose rates around reactor components was the presence of Co-60 due to activation of Co-59. It was too late to reduce Cobalt content in the design and construction of the Pickering A station but replacement components and later CANDU stations at home and abroad benefitted from this realization. This slide **[slide 6]** shows how Cobalt levels have been reduced over the years starting with the Bruce A station in the mid-70's.

In general, the feedback from Operations personnel to the Ontario Hydro designers has improved continuously over the years. In the early 1980's, the design organization established an occupational radiation safety engineering program in which a small group, with significant operational experience as Health Physicists and Engineers were fully integrated into the design process with a specific mandate to ensure that RP considerations were built into new system designs and modifications from the concept stage through to construction and operation. This kind of resource commitment is another example of management commitment.

This process had its greatest application in the design of the new Darlington Station (4 x 881 MWe) using a program known as the Occupational Radiation Management Program (ORMP), the objectives of which are to: **[slide 7]**

- emphasize occupational radiation dose as a parameter in the design process
- establish an occupational radiation dose target for the station in its design stage and to break this dose down into individual system design dose targets
- verify that the design achieves the dose targets through a four stage radiation management review process
- identify the normal operational, maintenance and inspection activities implicit in the station design that could be expected to involve significant dose expenditure and to estimate dose expenditures
- provide direction to designer's efforts to reduce the dose and to describe the methods available for achieving dose reduction in the design stage

The radiation management review process consists of four stages as described below for all relevant engineered systems:

## Stage 1

In this stage, gross dose estimates are developed based on design data and prior operational exposure history at other stations. Areas are then identified where dose reduction can be achieved using techniques such as: **[slide 8]**

- elimination of equipment
- simplification and orientation of system components
- provision of adequate space for maintenance
- relocation of equipment into lower dose rate areas
- chemical control and purification of active systems
- extension of time intervals between scheduled maintenance
- use of radiation resistant materials
- provision of the means for quick removal of components for maintenance in low dose rate areas (eg shops)
- reduction in the amount of time for in situ maintenance including the use of special tools
- increased use of shielding

## Stage 2

In this stage, detailed dose estimates are made accounting for operation, maintenance and in-service inspections. The designs are then checked for simplification, reliability, reduction and ease of maintenance to optimize dose reduction. Included in this stage of the process are the system design engineer, operations staff, the station Health Physicist, shielding specialists, the station layout coordinator, reliability and maintainability specialists and the design radiation safety specialists.

## Stage 3

This stage consists of a followup on the decisions made in Stage 2 and an evaluation of the requirements of layout change and/or supplementary shielding to offset any problems encountered in Stage 2. A subset of the group involved in Stage 2 contribute to Stage 3.

## Stage 4

In this stage, design changes resulting from the previous stages are confirmed to have been implemented and that the resultant changes to dose estimates have been accounted for. Where dose targets cannot be met, further consideration is given to dose reduction measures.

Consider application of this process to the Main Moderator Circuit at Darlington for example. The Moderator System is a low temperature, low pressure system whose primary purpose is to moderate fission neutrons in the reactor core. The core portion of the system is housed in a large steel tank known as the calandria. As the moderator is exposed to high flux, it is a source of activation products including Co-60, N-16 and tritium. Annual dose targets for the system (per reactor unit) were set in Stage 2 of the ORMP at 30 rem external (gamma + neutron) dose and 10 rem internal (tritium) dose. Some of the design requirements (dose reduction measures) that were established were that: **[slide 9]**

* all piping in contact with heavy water is stainless steel with low cobalt content (< 0.1% by weight)

* all welds to be butt welded

* all rooms to be connected to the confinement ventilation system (ie dried to remove airborne tritium)

- all penetrations have been checked for adequate gamma and neutron shielding

More specific measures are then applied to each part of the circuit.

Overall, for the total four unit station, the initial Stage 1 dose estimates were about 1570 rem per year for maintenance, inspection, operations and some allowance for contingency. At the end of Stage 4, this had been reduced to 550 rem per year, a reduction by about a factor of 3 due to dose reduction measures in the design stage.

## REHABILITATION

Replacement of pressure tubes (the core of the Heat Transport (coolant) System) was always anticipated to be required at some point in the life cycle in CANDU plants. For Pickering A, this happened somewhat sooner than planned after discovery of a significant pressure tube leak (loss of coolant) in 1983 **[slide 10]**. The cause was ultimately determined to be delayed hydride cracking. As a result, a decision was made at that time to replace all pressure tubes (390 per unit) in all 4 units at the Pickering A station. The actual work commenced in 1985 on Unit 1 and terminated in 1992 with the completion of retubing work on Unit 4. This presented a major technical challenge since much of this work was to be done in high radiation fields. For a CANDU reactor, this is essentially a "heart transplant" conducted in a somewhat hostile atmosphere. The overall project is conducted in several phases including defuelling of the core, tube/component removal, inspections, new tube installation and waste removal. Since this involves highly activated components, it was recognized from the outset that a well planned RP program was required to maintain exposures ALARA. One of the first steps was to assign an experienced operational Health Physicist to the project team.

Again, integration of RP considerations with other engineering activities was a distinct advantage from the outset. Management commitment to maintaining doses to levels ALARA was crucial and consistent with corporate objectives for radiation safety.

This project involved a large volume of work in relatively high beams of gamma radiation and high general gamma fields. There were many elements of the RP program that contributed towards minimizing occupational exposure but some of the more significant ones were[3,4]: **[slide 11]**

- establishment of individual and collective dose targets at an early stage
- construction of a full scale mock-up facility on site of the reactor face and Fuelling Machine Vault (the containment). The facility was used to develop and test specialized tooling and train personnel in a nonradiological environment.
- training of multiple crews for a job series who worked as a team during training on a full scale mock-up and remained intact for the actual job execution.
- decontamination of the primary system (Heat Transport System) prior to retubing work using the Can-Decon process. Overall, this reduced radiation fields by a factor of between 5 and 6. The cost of this procedure has been estimated at roughly $4400 (Can) per rem saved for the overall retubing project[4] without consideration of future dose savings.
- design of a special 3 sided steel shielding cabinet behind which most of the reactor face work was done. A 1/4 inch thickness of lead was added to the front of the cabinet during the retubing of Units 3 and 4.

- extensive use of personal alarming dosimeters to prevent unplanned exposures

- an effective radiation safety organization and work planning process.

The collective dose for the entire project on all 4 units was approximately 1390 person rem, about 23% below the target of 1800 person rem **[slide 12]**. For units 1 and 2, actual collective doses had to be estimated since the appropriate mechanisms were not in place to distinguish between dose received from retubing activities and other sources in the station.

Individual doses were constrained by the following criteria:

- dose to be equalized to within +/-25% for equivalent trades/technical staff exceeding 500 mrem per year

- management and engineering review to be initiated for an individual dose total to exceed 1.3 rem/quarter or 3.0 rem/year

- 5 year rolling average to be below 2 rem/year

Typical average doses to the most exposed workers (those at the reactor face) throughout the project were 900 mrem per year and no individual exceeded regulatory dose limits of 5 rem per year or 3 rem per quarter.

## ELIMINATION OF RADIOACTIVE SOURCES

A unique radiological hazard of heavy water reactors is tritium in the form of tritium oxide as water or water vapour. Equilibrium concentrations of tritium theoretically approach 60-80 curies/kg in the Moderator System. In some years, tritium dose has been as high as 50% of a station's whole body dose. As tritium concentrations in CANDU Moderator and Heat Transport Systems grew in the 1970's, there was increasing concern that tritium exposure to our workers would be difficult to maintain at acceptable levels without addressing the source term. As a result, a decision was made in the early 1980's to build a tritium removal facility (TRF) to service the needs of all Ontario Hydro stations. That plant has been built on the Darlington site at a capital cost of roughly $120 M (Can) and first started up in 1988 and achieved sustained production in 1990. **[slide 13]**

The objectives of tritium removal are to:

- reduce occupational dose from tritium exposure
- reduce public exposure as a result of tritium emissions

A secondary objective was to exploit the commercial value of tritium for non-military uses. The process basically consists of catalytic exchange of tritium in the vapour phase followed by cryogenic distillation to separate the hydrogen isotopes. The end product (> 99% gaseous tritium) is immobilized on titanium getter beds for long term storage. To date, less than 1% of stored tritium has been sold for commercial uses such as the tritium lighting industry.

The designed decontamination factor is 35 for the tritium removal process (once through). So far, treatment has primarily focused on removal of tritium from Bruce and Pickering Moderator System. More recently, some water has also been processed for the Point Lepreau Station in New Brunswick. Approximately 90 million curies of tritium (6500 Mg of heavy water) have been removed and immobilized to date.

Not only does this technology provide opportunities for reducing chronic dose consumption from tritium but also reduces the consequences of acute events such as heavy water spills. A Moderator spill, for example, can result in several thousand MPCa (DACs) of tritium in the air above the spill. Normally, our workers are dressed in air supplied plastic suits when working on the Moderator System which provides excellent protection against inhalation and absorption through the skin of tritiated water. However, if unprotected, a worker could receive a dose in excess of regulatory limits in a matter of minutes at such concentrations.

Although collective tritium dose corporate-wide has decreased in recent years, this is partly an artifact. Purely by coincidence, the startup of the TRF occurred at about the same time as a regulated change in the dosimetric model for tritium which has the effect of reducing the dose commitment by 27% for the same intake[5]. We will need to carefully monitor our tritium dose consumption in the years ahead to ensure that we are receiving good return on our investment in tritium removal.

## TRAINING OF PERSONNEL/SELF PROTECTION PHILOSOPHY

Extensive radiation protection training of operating and maintenance personnel as well as supervisors, managers and engineering staff has been a cornerstone of Ontario Hydro's RP program from the beginning and is an element of the ALARA program that transcends all phases of project life cycle. **[slide 14]** This commitment to the self protection concept has no doubt been a major contributor to our performance in radiation protection. The overall program typically extends over a period of a few weeks with both generic and station specific components. The operating budget corporate wide for the radiation protection training program is of the order of $3 M (Can) annually. These are direct costs only, ie, it does not account for lost production time for the students which is of course significant. The program includes a mixture of classroom and skills training in such areas as: **[slide 15]**

- Radiological hazards and hazard levels associated with specific reactor systems
- Use of protective equipment and instrumentation
- Dosimetry
- Biological effects of radiation and risk
- Radiological work planning including contingency planning
- Emergency procedures

More advanced training is given to Shift Supervisors and Control Room Operators, in part to prepare them for RP examinations set by the regulator which are part of the licensing process for such staff.

To quote ICRP 55[6], **[slide 16]** *"The basic role of the concept of optimization of protection is to engender a state of thinking in everyone responsible for control of radiation exposures such that they are continuously asking themselves the question, Have I done all that I reasonably can to reduce these radiation exposures?"*

"Everyone responsible for control of radiation exposures" includes many people in our organization including the employees on the front lines doing the hands on work and their first line supervision. Some of the advantages to the self protection philosophy include: **[slide 17]**

- employees see radiation protection as a joint responsibility

- employees are able to integrate RP responsibilities directly into their work
- the individuals performing the work become a valuable source of information for future improvements to the radiological aspects of the work
- there is a reduction in the number of people required to do a task (normally no HP techs required)

Overall, this approach has worked well although clearly there are associated costs and problems. In our corporate culture, we have created an army of amateur Health Physicists in the field with the result that RP professionals and line supervisors are constantly challenged by employees and their representatives on the essential elements of ALARA application, ie what constitutes "low", "reasonable" and "achievable". Our labour unions, particularly, have become very active in the management of dose control and reduction largely through representation on joint committees at both the station and corporate level. This applies to both policy development and execution of work practices in the field. Although difficult to quantify, it is likely that labour influences often result in policies and programs which are not cost justified, ie go beyond reasonable efforts to reduce dose and minimize risk but these costs must be balanced against the benefits of having a radiologically informed workforce. Making these judgements on a day to day basis is more art than science.

## GOALS AND TARGETS

A number of times in this paper, reference has been made to various collective and individual dose targets. Establishing such targets and integrating their use into the managed system is an important part of any ALARA program. To repeat, *what gets measured gets done*. In establishing such targets, it is essential that they are:

- challenging but attainable
- stated in measurable terms
- consistent with corporate initiatives and policy
- accepted and embraced by those directly responsible for achieving them

There must be real ownership for dose targets by facility management just as for production, reliability and cost targets. Dose targets must not be viewed as belonging to the RP Manager, ALARA Engineer or Health Physicist even though they may be responsible for deriving them.

In Ontario Hydro, dose targets are set on a broad basis by policy for the overall nuclear program for both collective and individual dose. Collective dose targets are pyramided up to the corporate level by summing contributions from each station or nuclear facility based on a detailed analysis of annual operating plans and outage schedules. Within those targets are targets for specific jobs and shift crews. It is important that adequate information systems exist to monitor and report performance in a timely manner.

Ontario Hydro Nuclear policy on exposure management[7] contains the following explicit limits. **[slide 18]**

### Collective Dose Standard

≤ 85 rem/unit/year

In essence, this is intended as a long term average target for any given facility who are required to develop annual targets based on analysis of workload and diligent application of the ALARA principle.

Internal dose (tritium) ≤ 25% of collective dose

### Individual Dose Limits

- 5 year dose limit - total dose averaged over 5 years ≤ 5.0 rem
- single year dose limit ≤ 2.0 rem or ≤ 1.0 rem if lifetime dose ≥ 50 rem

## INFORMATION MANAGEMENT

The traditional technical tools of the RP specialists will continue to be challenged in the 1990's as dose limits and RP standards tighten and available dollars shrink. But perhaps the most exciting opportunities for further progress lie in the field of information management with the advent of personal computers and local area networks. As an example, for many years we have used a manual "Radiological Log" in our plants as a tool for all staff to record information on plant radiological conditions and events. This log is typically maintained in the main control room and reviewed by Operators and tradespeople prior to entering the field to do work. This system is gradually being replaced by computerized logs which will provide greater access to current and historical information at a number of locations throughout the plant.

Many other examples exist in dose control and work planning (eg, computerized Radiation Exposure Permits) all of which will ultimately contribute to dose reduction. The gap is also closing between dose control and dosimetry (dosimeter of record) with the emergence of electronic dosimetry. In Ontario Hydro, we are actively developing future strategy for our external dosimetry system and electronic dosimetry is certainly one of the options being seriously considered. We have been sponsoring and participating in testing of one such device for some time. Its clear advantage lies in providing real time data at the worksite. However, there are many issues to resolve yet in the use of this exciting new technology as a dosimeter of record including quality assurance, cost, user acceptance and regulatory approval.

## SUMMARY

Major progress has been made over the past three decades in control of occupational radiation exposure in the Ontario Hydro nuclear program [slide 19]. This has resulted from the collective efforts of workers, supervisors, designers, RP specialists and has been driven by senior management commitment to the ALARA principle. Investment in the self protection philosophy has also been a major contributor by facilitating integration of RP considerations into all aspects of the work programs.

Economic pressures will provide further challenges in the future to maintain this performance while remaining cost competitive. It is likely that fully exploiting the advantages offered by information management will play a crucial role in meeting this challenge.

## REFERENCES

1. Ontario Hydro Radiation Protection Regulations, Part 1. Nuclear Electric Generating Stations, November, 1962.

2. Ontario Hydro Radiation Protection Regulations, Part 1. Nuclear Facilities, July, 1993.

3. Mohindra, J.K., "CANDU Retube Project ALARA Integration", Ontario Hydro Report HSD-HP-92-37, January, 1993.

4. Mohindra, J.K., "Pickering Retube Operations Person-Rem Reduction Measures", Ontario Hydro Report HSD-HP-91-2, March, 1991.

5. AECB Regulatory Document R-100, "The Determination of Effective Doses from the Intake of Tritiated Water", August, 1987.

6. Annals of the ICRP, *ICRP Publication 55.* "Optimization and Decision-Making in Radiological Protection", Pergamon Press, 1989.

7. Ontario Hydro Policy 120, Radiation Exposure Management, Revision 3, 1994

## Author Biography

**Michael Haynes** is Manager of the Health Physics Department of the Employee Services Division of Ontario Hydro Nuclear. He has held a variety of positions in operational Health Physics over a 17-year career with Ontario Hydro at Bruce, NPD, the central (corporate) Health Physics group and served as Senior Health Physicist at the Darlington Station from 1984-1992. Prior to joining Ontario Hydro, he worked for the Ontario Cancer Foundation in radiobiological research. He has a B.Sc. in Physics from the University of Waterloo and an M.Sc. in Biophysics from the University of Western Ontario.

Ontario Hydro
1549 Victoria Street East
Whitby, Ontario, Canada
LIN 9E3

Phone: 905 430 2215, ext. 3202
Fax: 905 430 0628