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Radiological Environmental Monitoring Programs at Canadian Nuclear Facilities - A Practical Model for Follow-Up Activities under the Canadian Environmental Assessment Act

J.A Tamm
Atomic Energy of Canada Limited
Sheridan Science and Technology Park
Mississauga, Ontario
L5K 1B2

R. Zach
Atomic Energy of Canada Limited
Whiteshell Research Establishment
Pinawa, Manitoba
R0E 1L0

"Follow-ups are the most important but the most neglected and weakest provision in the Canadian Environmental Assessment Act"(Sadar 2000).

Abstract

Under the Canadian Environmental Assessment Act (the Act), a federal authority, if it considers it appropriate, is to design a follow-up program for a project undergoing a federal environmental assessment and arrange for implementation of that program. Under the Act a follow-up program means a set of activities for verifying the accuracy of the environmental assessment (EA) of a project and for determining the effectiveness of any measures taken to mitigate any adverse environmental effects resulting from the project.

The Act currently does not include regulations, guidelines, standards or procedures regarding the design, content and implementation requirements for follow-up programs (Canadian Environmental Assessment Agency [the Agency] 1999). Uncertainties also exist regarding the roles and responsibilities in designing, implementing, enforcing and auditing such activities. The Agency is presently specifying appropriate activities to address these issues. This paper considers the existing radiological environmental monitoring programs at nuclear facilities. Such programs consist of two types of monitoring - radioactivity releases from the facility via liquid and gaseous waste streams, and radioactivity in the environment at large, beyond the facility's immediate location. Such programs have been developed by AECL, Canadian nuclear utilities and uranium mining companies. Our analysis shows that these programs can provide a good model for follow-up programs under the Act.

1. INTRODUCTION

1.1 Environmental Assessment Requirements for Follow-Up Programs

To assist in achieving environmentally sound and sustainable development, most jurisdictions, be they national (Canada 1992, NEPA 1969), international (ECE 1994), or provincial (Ontario 1990), have developed environmental assessment (EA) processes. Such EA processes contain, among others, three basic elements which are to be applied to proposed projects or activities to:

1) identify potentially significant adverse environmental effects;
2) define measures to prevent or mitigate these; and
3) monitor, after mitigation, any residual effects as well as other components of the EA.

The Canadian federal EA process, defined in the Canadian Environmental Assessment Act (the Act) (Canada 1992), contains these three basic elements. In the Act the third element is referred to as a "follow-up program" (Figure 1).

The Act is binding on federal authorities, who, when they are required to conduct an environmental assessment, are referred to as responsible authorities. Section 38 of the Act assigns responsibilities to a responsible authority to design any follow-up program that it considers appropriate for a project and to arrange for implementation of that program. When a licence is required to construct, commission, operate or decommission a nuclear facility, the responsible authority is the Atomic Energy Control Board (soon to be known as the Canadian Nuclear Safety Commission).

The Act defines a follow-up program as having requirements:

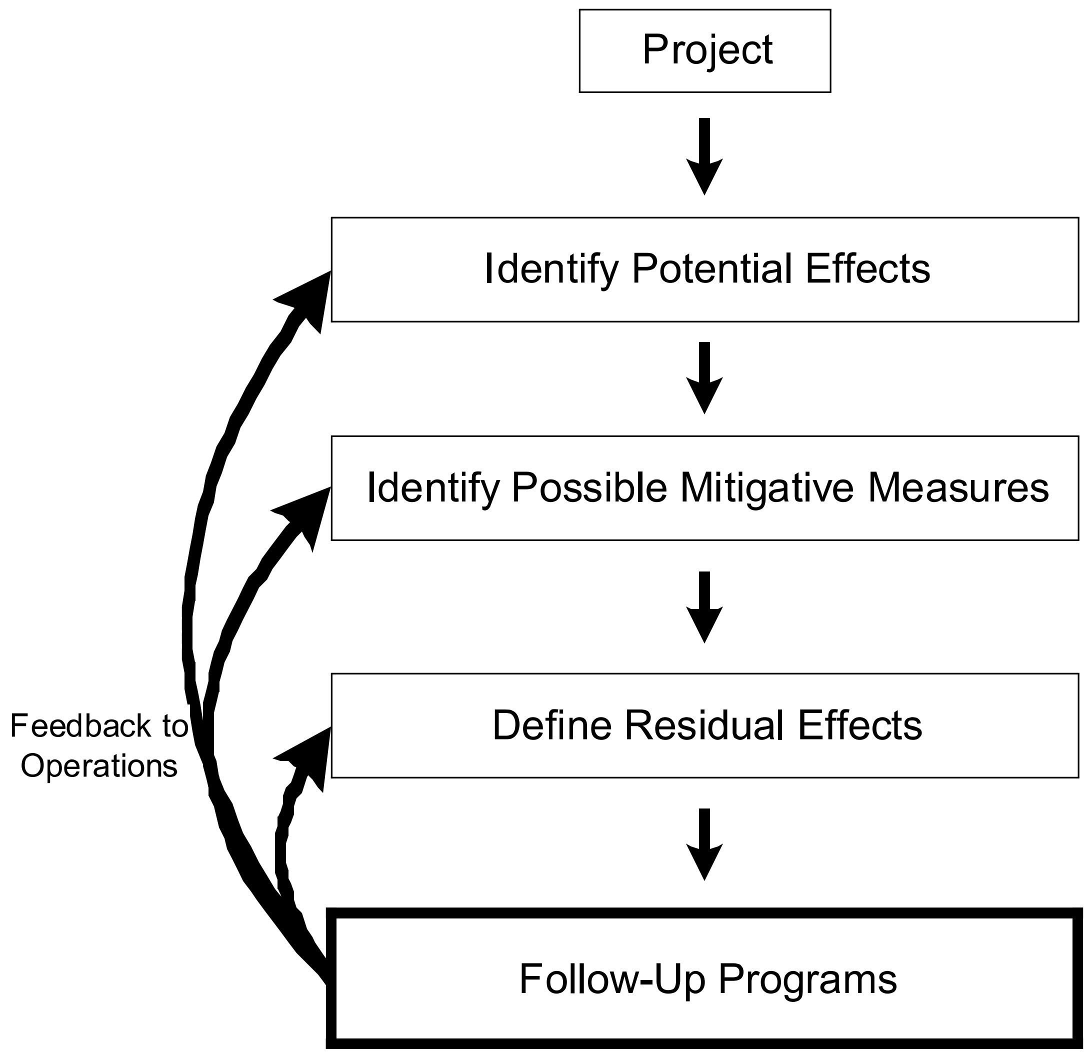
1. to verify the accuracy of the EA of a project (whether all potential effects and residual effects have been identified and whether they have been accurately assessed); and

2. to determine the effectiveness of any measures taken to mitigate any adverse environmental effects of that project.

1.2 Purpose of this Paper

Presently the Act does not have regulations, guidelines, standards or procedures regarding the design, content and implementation requirements for such follow-up activities (CEA Agency 1999). The guidance given in the Responsible Authority's Guide is brief (CEA Agency 1994). As a result few follow-up programs have been implemented under the federal EA legislation. There is therefore limited experience with extensive follow-up programs that include steps to ensure such programs are implemented, reported upon and audited, and whose results can be used as feedback to continuously improve the operational record of the project. The Agency is presently specifying appropriate activities to address these issues and looking for case studies to assist them with this effort.

Figure 1: Follow-Up Programs in an Environmental Assessment Process



In this paper we focus on radiological environmental monitoring programs for nuclear facilities and relate these programs to the requirements of a follow-up program under the Act. The radiological environmental monitoring programs described in this paper have been developed by AECL, Canadian utilities and uranium mining companies for Canadian nuclear facilities.

As previously mentioned, there is presently no specific guidance to define suitable components for a follow-up program under the Act. To develop such guidance information, the Agency has identified a range of issues that need to be addressed. In this paper we also use radiological environmental monitoring programs at nuclear facilities as a model to illustrate how some of these issues can be effectively addressed.

2. FOLLOW-UP REQUIREMENTS AT NUCLEAR FACILITIES

2.1 Regulated Requirements

Where EAs have been carried out for nuclear facilities, follow-up programs are required, such as for research reactors (the Medical Isotope Project, [AECB 1997]), nuclear power plants (NPP) (Point Lepreau NPP, [MacLaren Atlantic Limited Environmental Consultants *et al*. 1977]), licence renewals at research and development sites (Whiteshell Research Establishment site licence, [AECB 1998]), or for dry storage facilities for irradiated nuclear fuel (Gentilly 2 NPP, [BAPE 1994]). However, even without a nuclear facility having undergone a federal EA, operational monitoring requirements, with contents similar to those for follow-up requirements under the Act, are incorporated into the facility licensing requirements by the Atomic Energy Control Board (the Board). Operational experience from other nuclear facilities and comments from the Board on the owner's proposed program are used to develop such monitoring programs. The Board has the authority to evaluate such programs before it approves EAs or operating licenses for nuclear facilities. Monitoring facility operations and the effectiveness of mitigative measures in addressing potentially adverse operational effects on the environment are of key importance in defining such programs.

As explained above, operational monitoring programs at nuclear facilities are a licensing requirement. Therefore, in spite of several Canadian nuclear facilities not having undergone an EA process, they have designed, implemented, reported upon and continue to refine programs that can meet the two requirements of follow-up programs defined under the Act.

It should be noted that an operational monitoring program at a nuclear facility can contain many components, in additional to those for a radiological monitoring program. These components can include monitoring programs for measuring physical-chemical effects, ecological effects and socio-economic effects. For each of these components a number of sub-components can be considered. In essence, these sub-components relate to the familiar valued ecosystems components (VECs) and valued social components (VSCs) used in EAs.

The following is a list of potential VECs and VSCs commonly used in EAs of nuclear facilities:

- Physical-Chemical Effects (VECs)
  Soil
  Groundwater
  Surface water
  Sediment
  Air quality, including noise
- Ecological Effects (VECs)
  Terrestrial plants and animals
  Aquatic plants and animals
- Socioeconomic Effects (VSCs)
  Public health
  Worker health and safety

It needs to be recognized that such VECs and VSCs are valued elements that cannot always be directly quantified. Therefore, they are quantified in a follow-up monitoring program by the use of measurement endpoints. For protection of the public from radiation exposure, the measurement endpoints are radionuclide concentrations in liquid and gaseous effluents, and public radiation doses. These will be further explained in Section 2.2.1.

Depending on the type and location of each nuclear facility, VECs and VSCs can vary, which results in different requirements for operational monitoring programs. Therefore, early in the design of each project, there is the need to develop clearly established monitoring endpoints, the frequency or level of monitoring effort required, and the criteria for evaluating the monitoring results.

2.1.1 Expanding Monitoring Requirements

The scope of an operational monitoring program at a nuclear facility can be expanded by changes to the regulator's authority. In this context we note the Board has proposed an expanded environmental protection program (EPP) to reflect its new responsibilities under the soon-to-be enacted Canadian Nuclear Safety Act. The proposed EPP is concerned with physical, chemical and radiological effects for both people and the environment with its plants and animals (AECB 1999a). This is a much broader scope than considered by current effluent and environmental monitoring programs for both nuclear and non-nuclear industries.

2.1.2 Compliance Monitoring

The definition of a follow-up program under the Act does not explicitly consider compliance monitoring, i.e., monitoring to ensure regulatory guidelines and criteria are met. For a nuclear facility, however, such monitoring is a requirement set by the Board and, for non-radiological emissions, by provincial environmental protection agencies through the granting of permits and/or certificates of approval. The majority of monitoring currently done at nuclear facilities is concerned with compliance monitoring. Based on experience within the nuclear industry it would be our recommendation that compliance monitoring be considered as a necessary component of a follow-up monitoring program. Having such requirements as a component of an operational monitoring program would allow its integration with other components and avoid possible duplication of monitoring activities within the overall operational monitoring program.

2.2 Radiological Environmental Monitoring at Nuclear Facilities

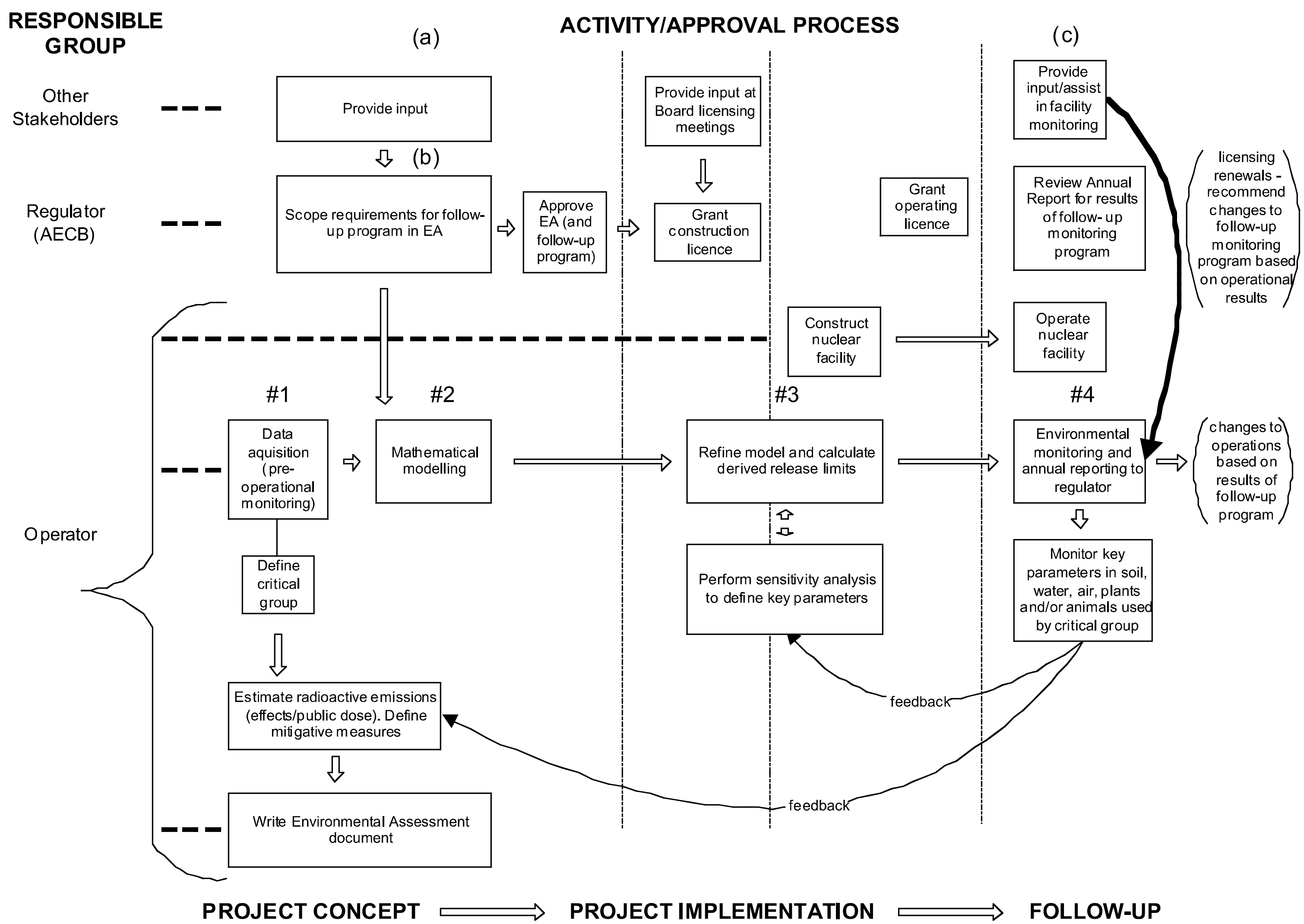
One of the most important environmental components that could be affected by the operation of a nuclear facility is public health. During operations low levels of radiological substances can be emitted in both air and water. These have the potential to increase the radiological dose that the public already receives from natural background sources of radiation. As explained earlier, public health is a VSC and, because of its importance, radiological monitoring programs are a licensing requirement as part of a nuclear facility's operational monitoring program. Other important components of radiological monitoring programs are concerned with worker health and safety, meteorology, and abnormal and accident events. This paper considers radiological monitoring programs concerned only with measuring and evaluating potential operational effects on public health from normal operations.

2.2.1 A Model for a Follow-Up Program as Defined in the Act

The process for developing a radiological environmental monitoring program is given in Figure 2. The first step (#1 in Figure 2), is the acquisition of background data concerning the environment and the people in the area surrounding the proposed facility. In addition to experience from presently operating nuclear facilities, guidance for what environmental factors should be monitored at this stage is also given by the International Atomic Energy Agency (IAEA 1986). For a NPP, it recommends that a database of measurements (e.g., from vegetation, sediment, fish, milk, air and water and other environmental media), including seasonal variations, be established two to three years before a NPP is put into operation. Although not required by the regulator, six years of monitoring data was gathered prior to initial station start-up by the Darlington NPP's Environmental Effects Monitoring Program (Ontario Hydro 1997a). This initial monitoring step is usually referred to as pre-operational monitoring because it establishes background data which can later be used to evaluate environmental monitoring results when the facility is operating.

As well, this data is used to define the "critical group", or those individuals who would be the most radiological exposed member of the public.

Figure 2: The Development of a Follow-Up Radiological Environmental Monitoring Program for Nuclear Facilities



Extremely conservative assumptions are made about this group's living and eating habits, to ensure there is considerable safety margins built into the dose calculations.

The magnitude of the doses to a member of the public from routine operational releases is too low to permit direct measurement. Instead the control is on the measurement and release of radioactive releases from the facility. To determine what the allowable release limits can be it is necessary to work backwards from the regulated public dose, presently set at 5 mSv per year. To calculate the operational release limits it is first necessary to develop a mathematical model of how the radionuclides, once released from the facility, operate in the environment. This is the second step in developing a radiological monitoring program (#2 in Figure 2). In combination with estimated gaseous and liquid effluent releases of radionuclides from the facility, the background data are used to establish an assessment (mathematical) model to trace radionuclides through the environment to people to establish dose estimates for the critical group. A model similar or analogous to that of the Canadian Standards Association (CSA 1987) is usually used. Obviously, such dose estimates are very important for securing approval from the regulator for the project to proceed. These dose estimates would be included in environmental assessments, and appropriate mitigative measures to ensure these are not exceeded, would be defined.

The third step at the construction and operational licensing stages (# 3 in Figure 2), involves refining the assessment model. To obtain the operating license for the facility, the assessment model used to estimate doses for the critical group is usually refined to a more detailed derived release model. It is used to calculate derived release limits (DRLs) for radionuclides released in gaseous and liquid effluents. The DRLs are set by considering the exposure pathways through the environment by which radionuclides from the nuclear facility could reach the critical group. For example, the public could be exposed to radiation found in water - from drinking, washing, swimming and/or irrigating crops which would later be eaten. The DRL is that rate of discharge for the specific radionuclide or group of nuclides, which if continued for one year, would expose a member of the critical group to the regulatory limit of 5 mSv per year. These calculated values therefore represent the regulated permissible upper limits governing controlled release of radionuclides from the facility. The DRLs form the basis of alarm setting and other operational limits and cover the significant radionuclides expected in both gaseous and liquid effluent streams. The DRLs vary for each nuclear facility. Although public dose, and the related DRLs are expressed on an annual basis, the rate of radiological releases are further controlled by limiting airborne emissions to weekly DRLs (i.e., annual DRL/52) and by limiting liquid emissions to monthly DRLs (i.e., annual DRL/12). An example of DRLs established for the Pickering B NPP are given in Table 1 and Table 2. In actual practice, operating targets or facility-specific emission limits, which are lower than DRLs (for example, set to not exceed a dose rate of 50 _Sv per year) are used as limits for the monitoring programs to provide further assurance that the public dose limits will not be exceeded.

Table 1
Derived Release Limits for Gaseous Effluents from the Pickering B NPP (Chase 1992)

Radionuclide/ Radionuclide Group	DRL	
Tritium (oxide)	1.8 x 10^5 Ci/week	6.6 x 10^{15} Bq/week
Noble Gases	4.4 x 10^4 Ci-MeV/week	1.6 x 10^{15} Bq-MeV/week
Carbon-14	4.6 x 10^3 Ci/week	1.7 x 10^{14} Bq/week
Mixed fission products containing Iodine	1.3 Ci/week	4.7 x 10^{10} Bq/week
Unidentified particulates	2.6 Ci/week	9.6 x 10^{10} Bq/week

Table 2
Derived Release Limits for Liquid Effluents from the Pickering B NPP (Chase 1992)

Radionuclide/ Radionuclide Group	DRL	
Tritium	1.9 x 10^6 Ci/month	6.9 x 10^{16} Bq/month
Carbon-14	3.1 x 10^2 Ci/month	1.2 x 10^{13} Bq/month
Gross Beta/Gamma Activity	2.2 x 10^1 Ci/month	8.1 x 10^{11} Bq/month

Environmental monitoring (#4 in Figure 2) operates in tandem with effluent monitoring as it is concerned with the long-term fate of the released radionuclides beyond the facility. It focuses on cumulative radionuclide levels in various environmental media, such as surface water, groundwater, soil, and food eaten by people. Measured values in these media can be compared with the corresponding values estimated by the derived release model to provide validation. At the same time, the model can be subjected to sensitivity analysis to determine which of its parameters and pathways are most important in determining DRLs. The radiological environmental monitoring program can thus be made more efficient and cost-effective by monitoring only these parameters and pathways. Such analysis represents an important feedback loop indicated in Figure 2 (from Step #4 to #3).

The EA for a nuclear facility, and its radiological environmental monitoring are closely integrated and so are a good model for follow-up programs under the Act. Of the two requirements for a follow-up program (Section 1.1), effluent monitoring is more concerned with mitigative measures to reduce contaminant releases from a facility, while the environmental monitoring is more effective for verifying the accuracy of effects predicted in an EA for various VECs and VSCs.

Depending on the monitoring results, modifications may need to be made to facility operations. For example, in the 1980s and early 1990s, the environmental monitoring program at AECL's Chalk River Laboratories (CRL) indicted increased radioactivity levels in the surface environment on the CRL site and in discharges to the Ottawa River. They were caused by radionuclides migrating from historic and other wastes into groundwater. Clearly, mitigative measures being used at that time to confine these wastes were not sufficiently effective to prevent contamination. As a result of the increased levels of radioactivity in the surface environment, several new mitigative measures were undertaken, including groundwater cleanup.

Two groundwater cleanup system were installed, the first in 1993 and the second in 1996 to remove radionuclides such as ^{60}Co, ^{137}Cs, and especially ^{90}Sr. Basically, the systems collect contaminated groundwater in sumps or wells. The water is then pumped to the surface for treatment before being discharged to the surface environment. Treatment involves chemical conditioning, precipitation and filtration (Vijayan et al. 2000). Process wastes are solidified, put into metal drums and stored in bunkers at CRL. In 1997, about 3.1×10^6 L of groundwater was treated and about 4.9×10^9 Bq of ^{90}Sr were removed (AECL 1999). Environmental monitoring results show that ^{90}Sr contamination in the environment has now stabilized and has started to decline. However, because of time delays between groundwater contamination and surface environment contamination, only continued environmental monitoring can establish the effectiveness of the groundwater cleanup systems. This feedback from operational monitoring is illustrated in Figure 2, "changes to operations based on results of follow-up program".

In summary then, through long-term application and improvements by nuclear operators, radiological effluent and environmental monitoring programs have become highly sophisticated, and have been very successful in protecting the public from radiation exposure, and in providing evidence to assure both the regulator and the public that the public dose criterion is not being exceeded and thus public health is being protected. Because of this it is valuable to consider these programs as a model to satisfy the requirements for a follow-up program under the Act.

2.3 Applicability of Nuclear Facility Monitoring to an EA Follow-Up Program

To provide an EA context it must be recognized that radiological environmental monitoring programs have been developed to measure a critical environmental component (VSC) for nuclear facilities - protection of the public from radiation exposure, and, furthermore, that corresponding measurement endpoints have been defined - radionuclide concentrations in liquid and atmospheric effluents. As has been demonstrated, such monitoring programs can be used to meet the requirements of the Act for follow-up programs (Figure 1). The radiological environmental monitoring program can therefore be used to:

1. evaluate/verify, once the facility is operating, whether effects (e.g., radionuclide concentrations in various media resulting in a predicted public dose) have been accurately predicted in the EA; and

2. assist with assuring that these predicted doses are not exceeded during operations, that is, that the mitigative measures are operating as predicted. If not, the monitoring results provide feedback to assist in determining what aspects of the facility operations need to be modified.

As previously discussed, radiological environmental monitoring programs also satisfy a third requirement, that of providing evidence that the facility is in compliance with the regulated public dose limits.

2.3.1 Solving Additional Agency-Defined Issues

Reporting Results of a Radiological Monitoring Program

One of the present issues with follow-up programs identified by the Agency (CEA Agency 1999) - that of capturing, sharing and effectively retaining information from such programs - is satisfied by radiological monitoring programs. Each nuclear facility reports on an annual basis the results of its radiological monitoring program (e.g., AECL 1999) (#4 in Figure 2). These reports are retained and made available to the public. Results of such reports can be used to provide reassurance to the public that radiological doses from the facility are within regulatory limits and also to indicate that compliance monitoring requirements have been met. In addition, as a separate initiative, the operators of CANDU NPPs also report on a regular basis their environmental monitoring results, and operational experiences. This information is retained and made available to all members of the CANDU Owners Group. The results of such monitoring programs can be used to improve facility operations and to evaluate the effectiveness of the components of operational monitoring programs.

Roles and Responsibilities for Carrying Out the Radiological Monitoring Program

A second challenge for follow-up programs identified by the Agency is that the roles and responsibilities for carrying out such programs are presently poorly defined. These roles are reasonably clearly defined for the nuclear industry. The Board, in its role as a responsible authority, makes the definition of a radiological monitoring program (as part of a follow-up program) a compulsory requirement of the EA, whether for a screening

(Pickering EA Scoping document, [AECB 1999b]) or comprehensive study (Bruce Used Fuel Dry Storage Facility Environmental Assessment, [Ontario Hydro 1997b]). Scoping for such a program is now being carried out with input from a variety of stakeholders - expert federal departments, provincial and municipal organizations and a variety of potentially affected public groups within the area of the facility [(a) and (b) in Figure 2]. As the responsible authority delegates the preparation of the EA to the proponent, the requirement to define the detailed program falls on the proponent. Thus, operators of nuclear facilities are expected to develop, fund, manage and report results from a radiological monitoring program. With major nuclear facilities, such as the newly opened uranium mines in Saskatchewan, the public can also have a formal role to play in developing, carrying out and reporting on such follow-up monitoring programs [(c) in Figure 2] (Liskowich 1999).

3. SUMMARY AND CONCLUSIONS

In this paper we show how radiological environmental monitoring programs at nuclear facilities can be used as a model for satisfying the requirements of a follow-up program, as defined for environmental assessments under the Act. The various components of a radiological monitoring program have been described in an effort to illustrate how the program can satisfy the two requirements defined in the Act. A radiological monitoring program can be used to effectively evaluate some of the effects predicted in an EA. Results from such a program can also be used to evaluate the effectiveness of mitigative measures and can indicate if operational changes are required. Data obtained from such monitoring programs also serve to demonstrate compliance with regulatory limits. The role and responsibilities of the facility operator and licensing authority are understood, with the role of other stakeholders continuing to evolve. The results of the radiological monitoring program are retained and can be used by a proponent of a similar facility for preparing part of its follow-up program. By making such information public, assurance can be provided to the public that adverse effects are not occurring from a facility's operation and regulatory criteria are being met. We trust our example will assist the Agency in developing guidance for follow-up programs in future EAs.

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