PUBLIC DOSE FROM A MULTI-UNIT CANDU SITE COMPARED WITH SITE LIMIT AND NATURAL BACKGROUND RADIATION

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ABSTRACT

Beyond the exclusion area boundary (EAB) that surrounds a CANDU® site, the maximum annual dose to members of the public, during normal operation, must comply with the national regulatory limits of the country in which the station is located. The Wolsong site, located on the south-east coast of the Republic of Korea, has four CANDU 6 plants, either operating or under construction. The Korean Electric Power Company (KEPCO) has proposed expanding the site to the north. The extended site could conceivably accommodate six CANDU 9 plants with an EAB at a 500-m radius. This study calculates the public dose at the EAB around the extended Wolsong site under normal operation. The work shows that the site could accommodate four CANDU 6 and six CANDU 9 plants without exceeding the annual dose allowed to a member of the public at the EAB, and giving only a small annual dose to the most-exposed member of the public living at the EAB.

1. INTRODUCTION

The small radiation exposure to members of the public from normal operation of CANDU nuclear power stations is dominated by the contribution from airborne effluents, more specifically from the release of tritium, ^{14}C and noble gases into the atmosphere. The noble gases considered were ^{85m}Kr, ^{87}Kr, ^{133}Xe, ^{135}Xe, ^{41}Ar; the radioiodines were ^{131}I and ^{133}I and the airborne particulates were ^{95}Zr and ^{95}Nb. For the liquid pathway, a more complete list of radionuclides was considered. Although both the airborne and the liquid pathways have been modelled in this study, the major part of the annual exposure can be attributed to airborne releases.

Currently, the Canadian limit on annual dose to the most-exposed member of the public under normal operation is 5000 mSv/a. This regulatory limit will soon change to 1000 mSv/a as Canada adopts the 1990 recommendation of the International Commission on Radiological Protection, ICRP 60 (1991). In the Republic of Korea, the annual dose limit for members of the public is 250 mSv/a. These limits apply to each site, regardless of the number of units on a particular site.

2. SITE DESCRIPTION

To demonstrate compliance with the Korean dose limits, AECL has calculated the annual dose from airborne and liquid effluents from 10 CANDU units on an extended Wolsong site. The layout of the proposed site is shown in.

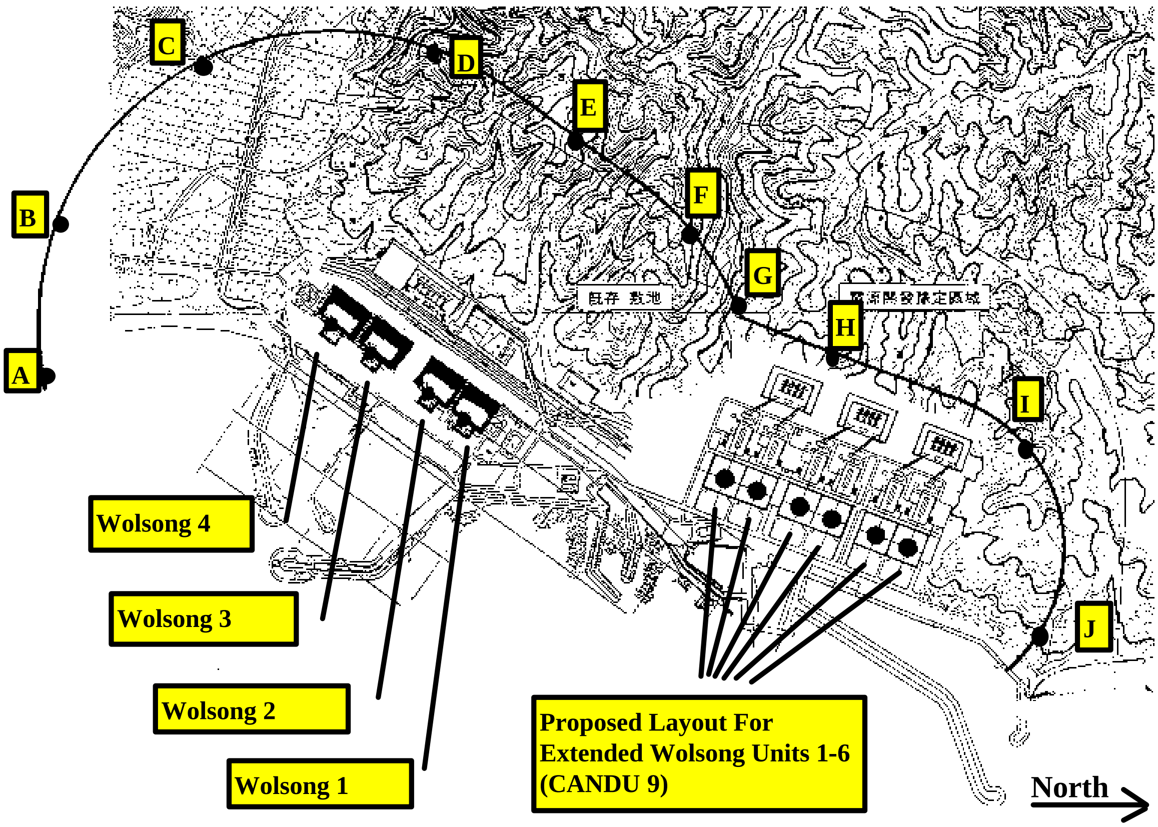

Figure 1 Extended Wolsong Site: Proposed Layout and Location of Exclusion Area Boundary

The Wolsong site, located on the south-east coast of the Republic of Korea, is surrounded by mountains to the north and west, a beach to the east and a village to the south. Clearly, the topography varies widely, and the method used to calculate the maximum annual dose from such a site should account for this. The analysis takes into account topography, building wake effects, and each unit's different annual emissions, which reflect design features.

3. DOSE CALCULATIONS

Because the prescriptive approach of the United States Nuclear Regulatory Commission (US NRC), has generally been mandated in Korea, the methodology described in US NRC Regulatory Guide 1.111 has been used for the treatment of atmospheric dispersion. That treatment has been coded in a computer program and is available as the software XOQDOQ (Sayendorf et al. 1982). The first part of the analysis consists of calculating an atmospheric dispersion coefficient, c/Q, and an atmospheric deposition coefficient, D/Q, from each reactor unit at different points on the EAB. The second part of the analysis consists of calculating the annual dose to the public by following the transport of emissions through atmospheric and aquatic pathways as they expose the critical age groups, as defined in US NRC Regulatory Guide 1.109. This methodology was programmed in an EXCEL 5.0 spreadsheet. Dose conversion factors were taken from ICRP 67 (1994), ICRP 69 (1995), ICRP 72 (1996) and the Federal Guidance Report No. 12 (Eckerman & Ryman, 1993).

3.1 Dispersion

3.1.1 Exclusion Area Boundary

As shown in Figure 1, the EAB around Wolsong units 1 to 4 (CANDU 6) is located at a 914-m radius. Many features were added to the CANDU 9 design to improve heavy-water-vapour recovery and decrease the amount of contaminants released to the atmosphere. Also, the containment design was strengthened to eliminate failure of containment isolation as a possible accident. It was therefore possible to reduce the land requirements and locate the EAB at a 500-m radius around Extended Wolsong units 1 to 6, (Figure 1).

3.1.2 Receptors

To calculate the atmospheric dispersion factors, c/Q, and the deposition coefficients, D/Q, 10 receptors were modelled at the intersection of the EAB with the sectors of the compass (i.e., north, south, east, west, north-east, etc.). These locations at which c/Q and D/Q were calculated are shown in Figure 1. Originally, there were 16 receptors, but the 6 seaward receptors (NE, ENE, E, ESE, SE, SSE) were discarded because no member of the public is found at these locations constantly. (The maximum public dose is based on a 24-h/day occupancy, 365 days per year). Exposures resulting from boating, swimming and other beach activities are modelled as part of the liquid pathways and do not depend on atmospheric dispersion.

3.1.3 Topography

Because the surrounding area is so varied (mountains, beach, village) and because terrain has a great effect on atmospheric dispersion, the topography affecting each reactor had to be considered in the c/Q and D/Q calculations. Accordingly, topography data were entered for all 16 sectors around each unit. Also, the location of each receptor on the EAB with respect to each unit differs; for example, receptor A, which is in the ESE sector with respect to Wolsong Unit 1, is located in the south sector with respect to unit EW (Extended Wolsong) 1, so each reactor unit was modelled separately. The labelling of the sectors starts with location A (south) and goes counter-clockwise, each sector being 22.5° wide.

3.1.4 Weather Data

In US NRC Regulatory Guide 1.111, the atmospheric dispersion factor is modelled as a combination of ground-level release and elevated release. The decision to treat the release as ground level or elevated depends on the ratio between the exit velocity from the stack and the wind speed. The XOQDOQ code calculates this ratio and adjusts the calculation accordingly. The adjustment is a function of the release height and the height at which the weather data were collected. For the Wolsong site, weather data at elevations of 10 and 58 m were available. However, this study used the 10-m weather data set, collected over a 7-year period and expressed as a frequency of occurrence of wind speed, stability category and direction. When the release is treated as ground level, the wind speed at an elevation of 10 m is used, and, when the release is treated as elevated, the wind speed input is adjusted by the XOQDOQ code. Generally, one finds that wind speeds increase with height. The treatment in the XOQDOQ code ensures that the wind velocities at the higher elevation of the stack are underestimated, so the atmospheric dispersion factor is overestimated by the XOQDOQ code by using the 10-m weather data.

3.1.5 Source

The amount of contamination released from each reactor unit is based on an average performance from CANDU reactors, modified to take account of improvements to the design. The releases used are projected releases and depend largely on how the plant is operated and on procedures. Efforts continue at AECL to find cost-effective ways of making these releases As Low As Reasonably Achievable (ALARA).

3.2 Pathways Modelled

For the airborne emissions, the following pathways were modelled: ingestion, inhalation, immersion, and external exposure. For liquid emissions, the following pathways were modelled: ingestion, immersion and external exposure. Each pathway is described in greater detail below. The concentration of radionuclides in all food, water, and air or the concentration of radionuclides deposited on the ground must first be calculated. Then, by multiplying the concentration by the annual consumption of each food, or by the amount of time spent being exposed to deposited activity, and by using a dose factor, one can derive an annual dose from each specific pathway (methodology described in US NRC Regulatory Guide 1.109).

3.2.1 Atmospheric Pathway

The exposure of the public is usually dominated by ingesting contaminated food such as milk, meat, grains, leafy vegetables, fruit and gimchi (Korean diet). The inhalation dose is obviously calculated from the inhalation of airborne radioactivity (breathing rate multiplied by the concentration of radionuclides in the air times a dose factor). For the immersion dose, as stated in USNRC Regulatory Guide 1.109, noble gases are the only contaminants considered to contribute to the dose, and the whole body dose is calculated for a semi-infinite cloud of activity having a uniform concentration of contaminants.

Chronic releases of airborne activity will produce, on average, low concentrations of contaminated air at ground level. Thus, an individual living in this environment would receive a small external exposure from any gamma radiation present. In the model used in US NRC Regulatory Guide 1.109, the activity is considered to accumulate for 15 years (typically, half of station life), and the dose to the individual is a simple calculation of dose rate above a plane source of contamination. For the radionuclides of interest to this study, the concentrations will have reached equilibrium. The amount of airborne contamination can be found from the average relative contamination in the air per unit of volume, and is calculated by the XOQDOQ code as c/Q. The amount of surface contamination can be found from the average relative deposition per unit area that is calculated by the XOQDOQ code as D/Q.

3.2.2 Aquatic Pathway

Doses received via the liquid pathway are usually much smaller than doses received from the airborne pathway (typically less than 6% of total dose comes from the liquid pathway). Foods contributing to ingestion dose from aquatic pathways include fish, crustaceans , molluscs and seaweed. Although US NRC Regulatory Guide 1.109 has no treatment for seaweed, this study included seaweed because it is a part of the Korean diet. We have treated seaweed as molluscs. The concentration of radionuclides in aquatic organisms depends on the concentration of radionuclides in the water. Equilibrium between concentration in contaminated sea water and concentration in the seafood is assumed. Water ingestion is not considered in this study because all releases from the Wolsong site are to the sea (non-potable water).The annual dose from immersion (swimming) is calculated by multiplying the concentration of radionuclides in the water by the amount of time spent swimming and by a dose factor. The body receives dose from gamma radiation in the water. External dose can come from boating (when the body is exposed to gamma radiation from the water) or from beach activities (when the body is exposed to gamma rays from activity deposited on the beach). The annual dose from boating depends on the amount of time spent on the water and the amount of activity in the water. The annual dose from beach activity and sunbathing depends on the amount of contaminants deposited on the beach, which in turn depends on the activity in the water, and on the amount of time spent on the beach.

4. RESULTS

Annual doses are given in Tables 1 and 2 for the whole body and for the most affected organ. Table 1 shows the sum of all doses from airborne releases from all 10 reactors, whereas Table 2 shows the sum of the doses from liquid releases.

The maximum whole-body dose from airborne releases is 63 mSv/a to the whole body of a child (Table 1), and the maximum whole-body dose from liquid releases is 1.5 mSv/a (Table 2), for a total of 65 mSv/a from all 10 CANDU nuclear reactors (Table 3).

Table 1 Doses From Airborne Releases, in mSv/a

	Whole Body				Gastro-Intestinal Tract			
ISOTOPES	**Adult**	**Teen**	**Child**	**Infant**	**Adult**	**Teen**	**Child**	**Infant**
^{3}H	21.90	22.83	25.89	6.03	21.90	22.83	25.89	6.03
^{14}C	21.36	23.49	25.82	0.47	21.84	24.04	28.13	0.24
Particulates	0.02	0.03	0.04	0.01	0.08	0.10	0.17	0.00
Iodines	0.01	0.02	0.03	0.00	0.00	0.00	0.00	0.00
Noble Gases	11.48	11.48	11.48	11.48	0.00	0.00	0.00	0.00
Total	**54.77**	**57.84**	**63.26**	**18.00**	**43.82**	**46.97**	**54.19**	**6.27**

Table 2 Doses From Liquid Releases, in mSv/a

	Whole Body				Gastro-Intestinal Tract			
ISOTOPES	**Adult**	**Teen**	**Child**	**Infant**	**Adult**	**Teen**	**Child**	**Infant**
^{3}H	0.09	0.09	0.09	0.00	0.09	0.10	0.09	0.00
^{14}C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Particulates	0.70	0.92	1.42	0.00	4.70	6.01	10.14	0.00
Iodines	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Noble Gases	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**0.80**	**1.02**	**1.51**	**0.00**	**4.79**	**6.10**	**10.35**	**0.00**

Table 3 Doses From Airborne plus Liquid Releases, in mSv/a

	Whole Body				Gastro-Intestinal Tract			
ISOTOPES	**Adult**	**Teen**	**Child**	**Infant**	**Adult**	**Teen**	**Child**	**Infant**
^{3}H	21.99	22.92	25.98	6.03	21.99	22.92	25.98	6.03
^{14}C	21.36	23.49	25.82	0.47	21.84	24.04	28.13	0.24
Particulates	0.73	0.95	1.45	0.01	4.77	6.11	10.31	0.00
Iodines	0.01	0.02	0.03	0.00	0.00	0.00	0.00	0.00
Noble Gases	11.48	11.48	11.48	11.48	0.00	0.00	0.00	0.00
Total	**55.57**	**58.86**	**64.76**	**18.00**	**48.61**	**53.07**	**64.42**	**6.27**

Maximum annual doses to the most-exposed organ, in this case the gastro-intestinal tract, are also given in Tables 1, 2 and 3, for airborne, liquid and total releases respectively. For liquid releases, the gastro-intestinal tract receives a higher dose than the whole body does. However, when all releases are taken into account, organ doses are always lower than whole-body doses.

5. COMPARISON OF RESULTS WITH LIMITS

The maximum annual dose to the most-exposed member of the public, under normal conditions, from the extended Wolsong site (10 reactor units) is 65 mSv/a. This is well below the Korean limit of 250 mSv/a.

6. COMPARISON OF RESULTS WITH NATURAL BACKGROUND

Background radiation is found in naturally occurring elements in rocks and soil, and in cosmic rays. The Canadian average natural background radiation is about 3000 mSv/a, varying according to altitude and soil composition and whether one lives in a basement (radiation from radon). The Korean average background radiation is about 2000 mSv/a (Figure 2).

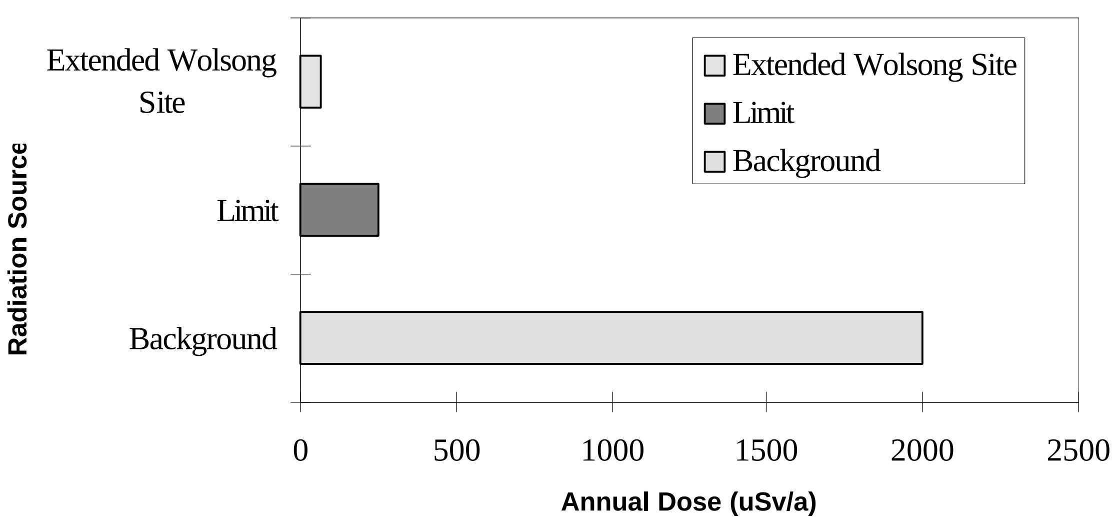

Figure 2 Annual Dose From Extended Wolsong Site Compared With Annual Limit And Background Radiation

7. CONCLUSIONS

Compared with background radiation (about 2000 mSv/a), doses from a nuclear power station with 10 reactor units at the Wolsong site in Korea are insignificant (65 mSv/a). Consequently, there is no constraint in adding an extra 6 CANDU 9 units to the 4 CANDU 6 units already operating or committed for the Wolsong site.

Despite this already low level of radiation to the public under normal operations, scientists at AECL are still working to find cost-effective ways of lowering doses from power plants that are consistent with the ALARA (As Low As Reasonably Achievable) philosophy. The new generation of power plants, CANDU 9 reactors, includes many features designed to reduce atmospheric releases.

One must also realise that the maximum annual dose from the reactor site would apply only to someone living right at the station boundary, eating only local food and drinking only local milk that had all been grown or produced in the sector corresponding to the person's location. Also, the annual dose decreases as the distance from the power plant increases. Thus the average individual receives an even more negligible dose from the power plant.

REFERENCES

U.S. Nuclear Regulatory Commission, Regulatory Guide 1.111, "Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors".

U.S. Nuclear Regulatory Commission, Regulatory Guide 1.109, "Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I", Washington, D.C. Revision 1, 1977 October.

ICRP (International Commission on Radiological Protection), "1990 Recommendations of the International Commission on Radiological Protection, Annals of the ICRP Vol. 21(No. 1-3) (ICRP Publication 60), 1991.

ICRP (International Commission on Radiological Protection, "Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 2", Annals of the ICRP Vol. 23(No. 3,4) (ICRP Publication 67), 1994.

ICRP (International Commission on Radiological Protection), "Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 3", Annals of the ICRP Vol. 25(No. 1) (ICRP Publication 69), 1995.

ICRP (International Commission on Radiological Protection), "Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 5", Annals of the ICRP Vol. 26(No. 1) (ICRP Publication 72), 1996.

Eckerman, K.F., and Ryman, J.C., "External exposure to Radionuclides in air, water and soil", Federal Guidance Report No. 12 (EPA-00402-R-93-081), 1993.

J.F. Sayendorf, J.T. Gold and W.F. Sandusky, NUREG/CR-2919:"XOQDOQ: Computer Program for the Meteorological Evaluation of Routine Effluents at Nuclear Power Stations", 1982 September.

KEY WORDS

Dose, public, limits, background, exposure, Wolsong, releases, pathways, airborne, liquid, CANDU 9