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Screening assessment of dose rates to wildlife related to the Nuclear Medicine Mo99 Facility, ANSTO, March 2017

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Definitions and Abbreviations

The following definitions have been used in this document:

ANM: ANSTO Nuclear Medicine

ANSTO: Australian Nuclear Science and Technology Organisation

ARPANSA: Australian Radiation Protection and Nuclear Safety Agency

CWWTP: Cronulla Wastewater Treatment Plant

EIS: Environmental Impact Statement

IAEA: International Atomic Energy Agency

ICRP: International Commission on Radiological Protection

LHSTC: Lucas Heights Science and Technology Centre

LLLW: Low Level Liquid Waste

OPAL: Open Pool Australian Light-water Reactor

TLD: Thermo-luminescent detectors

CR: Concentration Ratio

Summary

ANSTO has performed a screening assessment on potential dose rates to environmental receptors (wildlife) associated with the planned ANSTO Nuclear Medicine (ANM) Mo99 Facility. The ANM facility will be located on the 50 hectare ANSTO Lucas Heights site, which is surrounded by a 1.6 km radius buffer zone owned by the Commonwealth or its Agencies. The buffer zone is used by humans for recreational purposes and is home to a range of plant and animal wildlife. During its routine operations in producing medical isotopes and performing research, ANSTO releases small amounts of radionuclides through stack emissions and, after testing, through liquid discharges to the public sewer system. The purpose of this assessment is to use a standard screening approach to determine if potential dose rates to local wildlife from future releases, including the ANM Mo99 Facility, are below international benchmarks.

The assessment used methods from international best practice as laid out by the ARPANSA Guide: Radiation Protection of the Environment, which is consistent with current approaches set forth by the International Commission on Radiological Protection (ICRP) and the International Atomic Energy Agency (IAEA). The screening evaluations considered exposure to a range of terrestrial organisms in the buffer zone from stack emissions via the air pathway, and, to a range of marine organisms near the ocean outlet at Potter Point, New South Wales via the liquid effluent pathway. Dose assessments were performed using the ERICA tool with radioactivity concentrations for air and water determined from data collected during routine monitoring of stack emissions and effluent releases at ANSTO. Concentration values along air and water pathways were overestimated, consistent with an approach of using conservative assumptions in this screening assessment.

In summary, despite using overestimates for radioactivity concentrations associated with ANSTO's emissions, results indicate potential risk quotients that are below standard benchmarks for all organisms and all pathways considered. Dose rates to organisms were determined to be below the lowest benchmark for potential harmful effects (10 µGy hr^{-1}). These results are consistent with previous studies in determining no significant impacts from ANSTO effluents. Therefore, potential radioactivity releases from the ANM Facility are unlikely to impact local wildlife. Although projected dose rates are low, the release of low levels of radionuclides in air and water discharges indicates the need for ongoing monitoring and periodic re-evaluation.

Report

1.1 Background

The proposed ANSTO Nuclear Medicine (ANM) Mo99 project is for a new purpose-built fission product ^{99}Mo production facility. The ^{99}Mo product will be used at ANSTO and overseas for the manufacture of technetium 99m (^{99m}Tc) generators. These ^{99m}Tc generators are used in nuclear medicine clinics to produce sterile solutions, which are subsequently used in many diagnostic procedures. The Mo99 project has importance in helping meet Australian and world-wide demand for nuclear medicines.

A dose assessment was required to investigate the potential for radioactivity exposure to wildlife when the new ANM Facility becomes operational. The proposed location for the new building and facility is within ANSTO's main fenced site at Lucas Heights, NSW, in the reactor precinct near the existing OPAL research reactor. The ~50 hectare ANSTO Lucas Heights site is surrounded by a 1.6 km radius buffer zone which is owned by the Commonwealth or its Agencies. The buffer zone is home to a range of plant and animal wildlife which are exposed to ANSTO stack emissions via the airborne discharge pathway. In this assessment, selected plants and animals, known to occur in the buffer zone, were represented by standard reference organisms (Table 1).

Two main environmental pathways, airborne discharge and liquid effluent discharge, were identified for the screening analysis since they represent the primary mechanisms for transport of radioactivity from ANSTO into the natural environment. Liquid effluent from ANSTO is discharged via ANSTO's main discharge pipeline into the Sutherland Shire sewage network. The radioactivity concentration of the effluent is required to be diluted by at least a ratio of 25:1 (diluted by other public sources) upon entry to the Cronulla Wastewater Treatment Plant (WWTP). Testing has shown the dilution ratio is typically about 10 times greater at approximately 235:1. The combined sewage undergoes tertiary treatment at the Cronulla WWTP and is ultimately discharged into the ocean at the Potter Point ocean outlet. A range of marine plants and animals occur in the vicinity of the outlet and in this assessment, selected marine species were represented by standard reference organisms (Table 1).

All liquid discharged offsite from the ANM Facility will be included in ANSTO's liquid effluent discharge system, and will therefore not contribute radioactivity to stormwater runoff. Furthermore, the airborne radionuclide discharge from ANM will predominantly consist of noble gases, which do not accumulate in surface/stormwaters and are also unlikely to contribute to radioactivity in stormwater. Therefore, potential for impacts via the stormwater pathway is very low (much less than via the air and liquid discharge pathways) and this secondary pathway was not included in this screening assessment. Stormwater bunds at ANSTO are tested routinely and significant increases would be detected in the unlikely event of ANM releases impacting stormwaters.

1.2 Methods

The assessment used methods consistent with the ARPANSA Guide: Radiation Protection of the Environment (ARPANSA, 2015), and with current approaches set forth by the International Commission on Radiological Protection (ICRP)(ICRP, 2008) and the International Atomic Energy Agency (IAEA)(IAEA, 2013, 2014). These methods follow a framework for radiation protection that considers both humans and non-human wildlife (Figure 1).

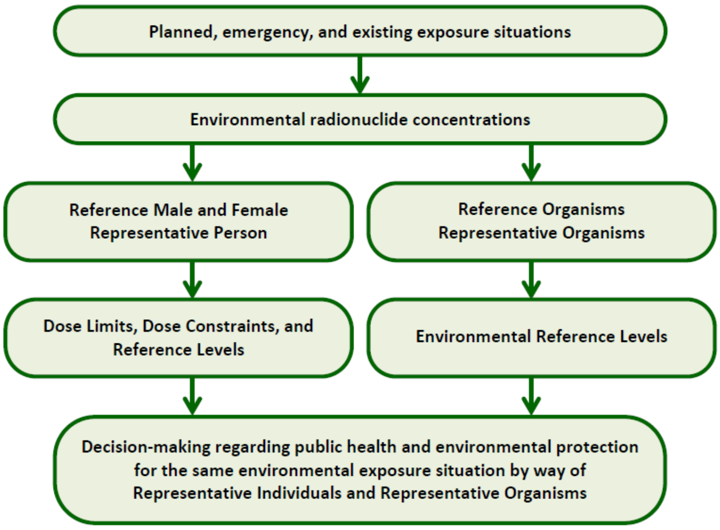

Figure 1. Framework for radiation protection of humans and non-human wildlife (ARPANSA, 2015).

Under this framework, for planned discharges, a screening assessment is first performed in which conservative (protective) release, transport, exposure data, and assumptions are used to determine if prospective risk exceeds the most stringent benchmarks for potential deleterious effects to wildlife. While the regulating agencies do not specify software tools, the current best-practice software available for this screening assessment is the ERICA-Tool (Brown et al., 2008), which has been developed in conjunction with input and coordination from key international oversight agencies (e.g. ICRP and the IAEA). The ERICA-Tool is a standard software package used in assessing dose rates to wildlife. The ERICA tool was used in Tier 2 mode which calculates dose rates for reference wildlife species, and returns screening risk quotients which considers the most sensitive standard species. For the screening assessment, marine and terrestrial species, known to occur in the exposed habitats, were selected with the aim of including a range of different phyla. Each identified species was represented in the ERICA tool by a standard reference organism (Table 1)

Table 1. ERICA reference organism categories and their corresponding representative species in areas near ANSTO discharges.

Reference Organism (ERICA categories)	**Scientific Name of representative site species**	**Common Name of representative site species**
Marine Organisms		
Sea anemone	*Actinia tenebrosa*	Waratah Anemone
Mollusc	*Brachidontes rostratus*	Beaked Mussel
Crustacean	*Jasus verreauxi*	Eastern Rock Lobster
Polychaete	*Sabellastarte australiensis*	Feather Duster Worm
Phytoplankton	Multiple Species	Phytoplankton
Macroalgae	*Ulva lactuca*	Sea Lettuce
Pelagic fish	*Girella tricuspidata*	Luderick
Terrestrial Organisms		
Grasses & Herbs	*Poaceae spp.*	Grass
Tree	*Acacia longifolia*	Acacia tree
Annelid	*Lumbricidae spp.*	Earthworm
Arthropod	*Acrididae spp.*	Grasshopper
Reptile	*Varanus varius*	Goanna
Mammal - small	*Wallabia bicolour*	Swamp Wallaby

In applying the screening method for this study, site data was used in a conservative (protective) screening approach. Table 2 describes the main inputs to the screening process and the amount of conservativeness applied. For the liquid discharge pathway, the key conservative assumptions included: assuming a 50% increase in the radioactivity concentration of ANSTO'S liquid effluent discharges from the proposed ANM Facility; assuming the minimum allowed dilution within the sewerage system (25:1) which is much less than the actual measured dilution (~235:1); and assuming no removal by the Cronulla (WWTP) tertiary treatment process, which, in fact partially removes many of the radionuclides from the liquid stream. For the air pathway, key conservative assumptions included: calculating dose rates to plants and animals in the N and ENE wind vectors, which are the directions with the highest transported air concentrations. Along these transects, the maximum air activity concentrations were used, and the wildlife receptors were assumed to be exposed 100% of the time at the point of highest air concentration.

Table 2. Screening process: data sources and assumptions.

Screening element	Screening Values	Notes
Liquid Discharge Pathway		
ANSTO liquid discharges.	Measured data, July 2013 to November 2016 (Table 3).	Measured at ANSTO prior to release into the public sewer system. For each radionuclide, used total Bq measured divided by total liquid discharged.
Assumption for prospective ANSTO discharges.	It was assumed that future liquid discharges with the ANM Facility would be 50% greater than current (2016) levels for all of ANSTO.	Advice for liquid effluent discharge projections was provided by ANSTO Waste Management Services, Waste Operations.
Dilution within the public sewer system.	Used minimum (25:1) dilution ratio required under the trade waste agreement.	Actual dilution ratio was calculated to be 235:1 (Environmental Monitoring dilution study, July 2016).
Treatment at the Cronulla WWTP.	Assumed no removal by Cronulla WWTP.	Highly conservative assumption. In actual practice, many of the radionuclides have high Kd values and will be efficiently removed at the Cronulla WWTP.
Discharge from Cronulla WWTP to marine waters.	Used the median of measured dilution value (14.4) for area <50 m from outlet.	As measured in tritium tracer studies (Twining and Hughes, 2008)
Occupancy of marine organisms.	Assumed full occupancy within 50 m of outlet.	This approach evaluates the exposure to a small group or individuals (not populations) in the

		immediate discharge area.
Uptake of radionuclides (Concentration Ratios – CRs) by organisms.	All default ERICA CRs were used.	The default CRs are generally considered to be conservative.
Dosimetry calculations.	Dose rates were calculated by the ERICA-Tool.	ERICA Tier 2 (for risk quotients and dose rates) was used for standard ERICA organisms. Both external (from water and sediment) and internal sources.
Benchmark for potential effects to organisms.	10 µGy/hr.	10 µGy/hr is the most conservative, stringent benchmark for assessing potential effects on individual wildlife. For detailed evaluations, a 400 µGy/hr benchmark is used for potential impacts on populations (not individuals).
Air Discharge Pathway		
Air activity concentrations.	Modelled data, quarterly for CY 2016 (Appendix A).	From routine ANSTO air release and transport modelling. Used two vectors, North and ENE, which are the directions with highest activity concentrations.
Assumption for prospective ANM discharges.	It was assumed that future air discharges for ANM would be comparable to current (2016) levels for all of ANSTO.	This is a conservative overestimate used for screening purposes.

Air at receptor locations.	Used the highest activity concentrations from 4 receptor locations along each transect (e.g. Library) to the far edge of the buffer zone at 1.6 km.	
Soil at receptor locations.	Non-noble gas radionuclides (e.g. Sr-90, iodine isotopes) were assumed to accumulate in top 10 cm of soil.	The soil inventory was subject to radiological decay, but no reduction was assumed for water or air erosion.
Occupancy of terrestrial organisms.	Assumed full occupancy at the locations of highest air concentrations.	
Uptake of radionuclides (Concentration Ratios – CRs) by organisms.	All default ERICA CRs were used.	The default CRs are generally considered to be conservative.
Dosimetry calculations.	Dose rates were calculated by the ERICA-Tool, and, for noble gases, the "Ar - Kr - Xe Dose Calculator" (Vives et al., 2015).	ERICA Tier 2 (for risk quotients and dose rates) was used for standard ERICA organisms. Dose conversion coefficients for noble gases are by reference (Vives et al., 2015).
Benchmark for potential effects to organisms.	10 µGy/hr.	10 µGy/hr is the most conservative, stringent benchmark for assessing potential effects on individual wildlife. For detailed evaluations, a 400 µGy/hr benchmark is used for potential impacts on populations (not individuals).

The water activity concentrations used for risk and dose calculations were determined using the discharge activity concentrations for all of ANSTO's liquid effluent releases (measured at ANSTO) between July 2013 and November 2016 (Table 3). Discharge activities were conservatively multiplied by 1.5 to represent the unlikely predicted increase (50%) to discharge from the ANM facility. Actual dilution in the sewerage system is measured periodically and in 2016 the dilution ratio was 235:1 (Environmental Monitoring dilution study, July 2016). However in this assessment, we applied a more conservative dilution ratio of 25:1 to the discharge activity concentrations, the minimum dilution required under the Trade Waste Agreement with Sydney Water Corporation. Finally, although metals and other adsorbing elements are removed by the Cronulla WWTP, this screening assessment assumed no removal. The effluent discharged at Potter Point disperses within the habitat area of the marine organisms considered and although screening practice allows consideration of large areas (that would include populations of organisms), we limited the exposure area to approximately <50 m from the discharge point. This allowed for a measured mixing ratio of 14.4:1 (Twining and Hughes, 2008) to be applied to the discharge activity concentrations. With the inclusion of these assumptions, the water activity concentrations used in the screening dose evaluation (Table 3) were conservative overestimates. As evidence of the conservative nature of the assumptions used in this screening assessment, the activity concentration of ^{137}Cs used in fish was 1.9 Bq kg^{-1}. This value is much higher than actual measurements of fish captured at Potter Point, none of which have exceeded minimum detection limits of 0.4 – 0.7 Bq kg^{-1}.

The air activity concentrations (Table 4) used for risk and dose calculations were derived from the routine stack monitoring results and the air pathway transport values, measured by ANSTO for purposes of dose evaluation for human receptors in keeping with the framework in Figure 1. The estimated effective dose to humans via the air pathway are modelled quarterly using the PC-Cream computer code, with the Lucas Heights weather station data and measured stack emissions as inputs. For wildlife, the screening assessment considered exposure to plants and animals spending 100% of their time in the buffer zone. More specifically, the exposure locations were on the N and ENE transects from within ANSTO to the far edge of the buffer zone. These two transects coincide with the directions of highest air activity concentrations as indicated by the PC Cream model. In addition, the screening assessment selected the highest air activity concentrations (Table 4) along these transects to use in the risk/dose calculations. From these air concentrations, contamination may build up in the soil. The screening assessment allowed for 50-years of radionuclide build-up in the top 10 cm of soils, and assumed no loss to air or water erosion (a highly conservative assumption). Note that the noble gases do not substantively accumulate in local soils, waters or non-human biota and therefore, air concentrations were used. From these assumptions the resulting air and soil activity concentrations used in the screening dose evaluation (Table 4) were conservative overestimates.

Table 3. Activity concentrations for radioisotopes measured in liquid effluent discharged from ANSTO between July 2013 and November 2016. Concentration values for water at the receptor site include the stated dilution ratios and increased release assumptions.

Isotope	Activity concentration discharged from ANSTO ($Bq\ L^{-1}$)	Activity concentration in water at receptor site ($Bq\ L^{-1}$)
Tritium	3.9E+02	1.1E+00
Chromium-51	4.3E+00	1.2E-02
Cobalt-60	2.2E-02	1.0E-04
Strontium-90	9.6E+00	2.7E-02
Molybdenum-99	6.3E-01	1.8E-03
Niobium-95	3.1E-01	9.0E-04
Caesium-134	5.1E-02	1.0E-04
Caesium-137	8.1E+00	2.3E-02
Hafnium-181	5.6E-02	2.0E-04
Iodine-131	1.6E+00	4.5E-03
Lanthanum-140	3.3E-02	1.0E-04
Radium-226	1.5E-01	4.0E-04

Table 4. Activity Concentrations for air discharge pathway. These activity concentrations are based on the highest air activity concentrations indicated by 2016 combined ANSTO air releases, along with an assumed 50-year radionuclide build-up in the top 10 cm of soils, with no assumed loss to air or water erosion.

Isotope	N transect Air ($Bq\ m^{-3}$)	N transect Soil ($Bq\ kg^{-1}$)	ENE transect Air ($Bq\ m^{-3}$)	ENE transect Soil ($Bq\ kg^{-1}$)
Tritium	1.93E-02		1.93E-02	
Argon-41	0.00E+00		0.00E+00	
Krypton-85	2.79E-09		1.29E-09	
Krypton-85m	2.41E-02		1.73E-02	
Strontium-90	4.60E-07	2.61E-03	4.30E-07	2.44E-03
Iodine-131	4.42E-04	2.79E-02	4.13E-04	2.60E-02
Iodine-133	4.81E-05	3.25E-04	4.81E-05	3.25E-04
Xenon-133	1.87E+01		1.05E+01	
Xenon-135	1.74E+00		1.12E+00	
Xenon-135m	2.41E-01		1.48E-01	

1.3 Results

The results of the assessment are provided using the standard concept of risk quotient, which is a measure of how the radiological risk to site organisms compares to a screening value, reflecting a standard highly conservative approach (e.g. considers exposure of the most radiosensitive species and comparison to the most conservative benchmark for potential effects). In practice, a risk quotient of unity, or higher, indicates site exposures do not pass the standard screening criteria and a more detailed site evaluation is needed. In this assessment, we evaluated risk quotients using the ERICA-Tool, Tier 2 mode, and found all risk quotients to be below unity (Table 5). The risk quotient values for marine organisms were up to 5 orders of magnitude higher than for the terrestrial organisms. However, the risk quotient approach is not comprehensive in this case as the risk quotients for the air pathway do not include exposure to noble gas isotopes (not available within ERICA-Tool). Therefore, in addition to risk quotients, this screening assessment also evaluated dose rates, which can be calculated for noble gas isotopes.

Table 5. ERICA Tier 2 Risk Quotients from all radionuclides available in the ERICA-Tool (noble gas isotopes are not available).

Water Pathway		**Air Pathway**	
Erica Organism	**Risk Quotient**		**Risk Quotient**[1]
Sea anemone	1.2E-01	Grasses & Herbs	2.7E-6
Mollusc	1.1E-01	Tree	2.7E-6
Crustacean	9.3E-02	Annelid	2.9E-6
Polychaete	2.2E-01	Arthropod	3.0E-6
Phytoplankton	7.0E-03	Reptile	3.0E-6
Macroalgae	1.2E-01	Mammal - small	3.3E-6
Pelagic fish	1.0E-03	Grasses & Herbs	2.7E-6

[1] The risk quotients for the air pathway did not include exposure to noble gas isotopes, which are not available within ERICA-Tool.

Dose rates to reference organisms (Table 6) were, in all cases, below the most conservative screening benchmark (10 µGy hr^{-1}) and far lower than the benchmark that would suggest impacts to populations (400 µGy hr^{-1}). The highest screening dose rates were associated with liquid discharge pathway, and the largest dose contributors were Nb-95, Hf-181, and La-140. However, these elements all have relatively high adsorption capacity, and a portion of these are likely to be removed by the tertiary treatment process at the Cronulla WWTP prior to release into the ocean.

For comparison, a separate set of dose rates to marine biota were calculated previously, in 2008, for the existing conditions at the time. The biota dose rates were lower and ranged between 8E-5 to 1.0E-2 µGy hr^{-1}. This previous study used the measured dilution for ANSTO's liquid effluent entering the Cronulla WWTP that year, as well as measured discharge activity concentrations for a set of selected radionuclides (Twining and Hughes, 2008). Therefore, the 2008 estimates of dose to biota resulting from routine ANSTO discharges are less conservative and considered more representative of actual dose values compared the overestimated values described in this study.

The calculated screening dose rates are comparable to existing ambient (background) dose rates from radionuclides of natural origin. Typical background dose rates range from approximately 0.1 to 1.0 µGy hr^{-1} for fish in the Pacific Ocean (Johansen et al., 2015). In addition, a separate study on radioactive iodine discharges was reported in 2011 which found dose rates to biota near the Cronulla discharge location also below the 10 µGy hr^{-1} benchmark. (Veliscek Carolan et al., 2011). It was found that the portion of the dose derived from ANSTO discharges was less than 2% (most came from medical facility discharges) further emphasising the low dose implications attributed to ANSTO discharges. The 2011 Iodine study also considered use of biosolids removed from the Cronulla WWTP for use in fertiliser applications. This could present another pathway to plants and animals via removal of ANSTO radionuclides from the liquid stream, into the biosolids, then subsequent exposure to crops and their consumers. The available data on the biosolid accumulation is too limited to warrant further calculation in this screening assessment, and it is recommended that future assessments consider this pathway in more detail.

Table 6. Conservative screening dose rates to reference organisms (µGy hr^{-1}) for both water and air pathways.

Water Pathway	**Anemone**	**Mollusc**	**Crustacean**	**Polychaete**	**Phyto-plankton**	**Macroalgae**	**Fish**
H-3	8.8E-06	8.8E-06	8.8E-06	8.8E-06	8.8E-06	8.8E-06	8.8E-06
Cr-51	1.5E-02	1.4E-02	1.3E-02	2.9E-02	4.3E-04	1.5E-02	2.3E-05
Co-60	3.5E-02	3.5E-02	3.3E-02	7.1E-02	9.1E-06	3.6E-02	6.4E-05
Sr-90	1.3E-03	2.3E-03	8.4E-04	6.9E-05	6.0E-04	4.2E-04	4.2E-04
Mo-99[1]	1.7E-03	8.4E-04	1.8E-03	1.8E-03	4.3E-07	5.4E-03	8.2E-06
Nb-95	3.9E-01	3.9E-01	3.6E-01	7.9E-01	2.2E-05	3.9E-01	2.2E-06
Cs-134	6.7E-04	6.5E-04	5.9E-04	1.3E-03	1.9E-07	6.6E-04	2.4E-06
Cs-137	4.0E-02	3.8E-02	3.5E-02	8.0E-02	2.2E-05	4.0E-02	3.5E-04
Hf-181[1]	1.7E-01	9.3E-02	4.0E-02	2.5E-01	1.7E-04	1.8E-01	4.3E-05
I-131	4.5E-03	4.9E-03	1.1E-04	4.6E-03	2.8E-04	2.2E-03	6.2E-06
La-140	5.1E-01	4.9E-01	4.5E-01	1.0E+00	6.3E-05	5.1E-01	4.4E-04
Ra-226	9.2E-03	4.8E-03	6.2E-03	1.0E-02	6.6E-02	6.5E-03	7.9E-03
Total	**1.2E+00**	**1.1E+00**	**9.3E-01**	**2.2E+00**	**7.0E-02**	**1.2E+00**	**1.0E-02**

Air pathway	Grasses & Herbs	Tree	Annelid	Arthropod	Reptile	Mammal - small
H-3	2.4E-05	2.4E-05	2.4E-05	2.4E-05	2.4E-05	2.4E-05
Ar-41	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Kr-85,85m[2]	4.6E-07	4.6E-07	3.3E-11	2.5E-07	1.6E-08	2.2E-08
Kr-87	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Kr-88	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Sr-90	1.0E-06	8.1E-07	9.0E-08	3.1E-07	6.4E-07	2.7E-06
I-131	2.6E-06	2.7E-06	5.8E-06	6.1E-06	6.2E-06	6.5E-06
I-133	4.9E-08	5.1E-08	1.2E-07	1.2E-07	1.3E-07	1.3E-07
Xe-133	2.5E-04	2.5E-04	1.3E-04	1.7E-04	1.0E-04	7.8E-05
Xe-135, Xe-135m[2]	2.4E-05	2.4E-05	1.6E-05	1.6E-05	9.3E-06	7.2E-06
Total	**3.0E-04**	**3.0E-04**	**1.7E-04**	**2.1E-04**	**1.4E-04**	**1.2E-04**

[1] The ERICA Tool did not provide for two of radionuclides present. Rather than omit, we have entered site data into ERICA using similar radionuclides (Tc-99 for Mo-99, and Ce-144 for Hf-181).
[2] The Noble Gas spreadsheet dose tool did not provide dose conversion coefficients for two radionuclides. Rather than omit, Kr-85m was included as a ratio of Kr-85, and **Xe135, 135m were included as ratios of Xe-133.

For the air pathway, the screening evaluation indicated a maximum total dose rate of 3E-04 µGy hr^{-1} when considering exposure to grasses and trees. The largest dose contribution was from xenon isotopes, followed by tritium. The evaluation used standard biota assessment tools (ERICA-Tool for most radionuclides), and, for noble gases, the Ar-Kr-Xe Radiological Impact Assessment Tool for Terrestrial Organisms: (Vives et al., 2015). Conservative assumptions were used (e.g. using maximum air concentrations from a one-year period, using the wind vector with the highest activity concentrations). These dose rates are many orders of magnitude below the screening benchmark (10 µGy hr^{-1}), and thus far lower than the level that would suggest impacts to populations (400 µGy hr^{-1}).

1.4 Conclusions

Despite highly conservative assumptions, results indicate potential risk quotients are below unity for all organisms and all pathways considered. Had risk quotients exceeded unity, a more detailed assessment would be warranted. Dose rates to organisms were also calculated and determined to be below the lowest benchmark for potential effects (10 µGy hr^{-1}) and thus far lower than the level that would suggest impacts to populations (400 µGy hr^{-1}). The predicted dose rates are for future conditions and were made using highly conservative assumptions and therefore do not reflect current conditions (they are expected to significantly overestimate current conditions). For the liquid discharge pathway, previous evaluations were published in 2008 and 2011, which also concluded that dose rates to exposed biota were well below benchmarks.

Although projected dose rates are low, the presence of radionuclides in air and water discharges indicates the need for ongoing monitoring and periodic re-evaluation.

Acknowledgments

This document was prepared by ANSTO staff members Mathew Johansen and Michael Corry, with data input from Richard Barton under project oversight by Rachel Ahyong. Review was provided by Tom Loosz and Catherine Hughes.

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