A Preliminary Assessment of Potential Impacts of Uranium Mining in Virginia on Drinking Water Sources

EXECUTIVE SUMMARY

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A large uranium reserve, estimated to be over 100 million pounds, was discovered at the Coles Hill site in Pittsylvania County, Virginia about three decades ago (see Figure ES-1). This reserve could be large enough to supply the fuel to all nuclear reactors in the United States for two years. There is interest in the mining and milling of these reserves, which are located upstream of John H. Kerr Reservoir (Kerr Reservoir) and Lake Gaston in southern Virginia. This report describes, and provides the results of, a preliminary assessment that investigated the potential impacts of a uranium tailings release on downstream water sources. Specifically, the assessment focused on the potential of a catastrophic failure of a uranium-tailings containment structure and subsequent discharge of uranium tailings into the Banister or Roanoke rivers and the resulting radioactive contamination in downstream water bodies including the Kerr Reservoir. The preliminary assessment aimed to address the following objectives:

- Estimate the amount of uranium-contaminated sediment and water that might reach Kerr Reservoir under normal and extreme precipitation events; and

- Estimate the potential increase in radioactivity levels and other contaminants in Kerr Reservoir.

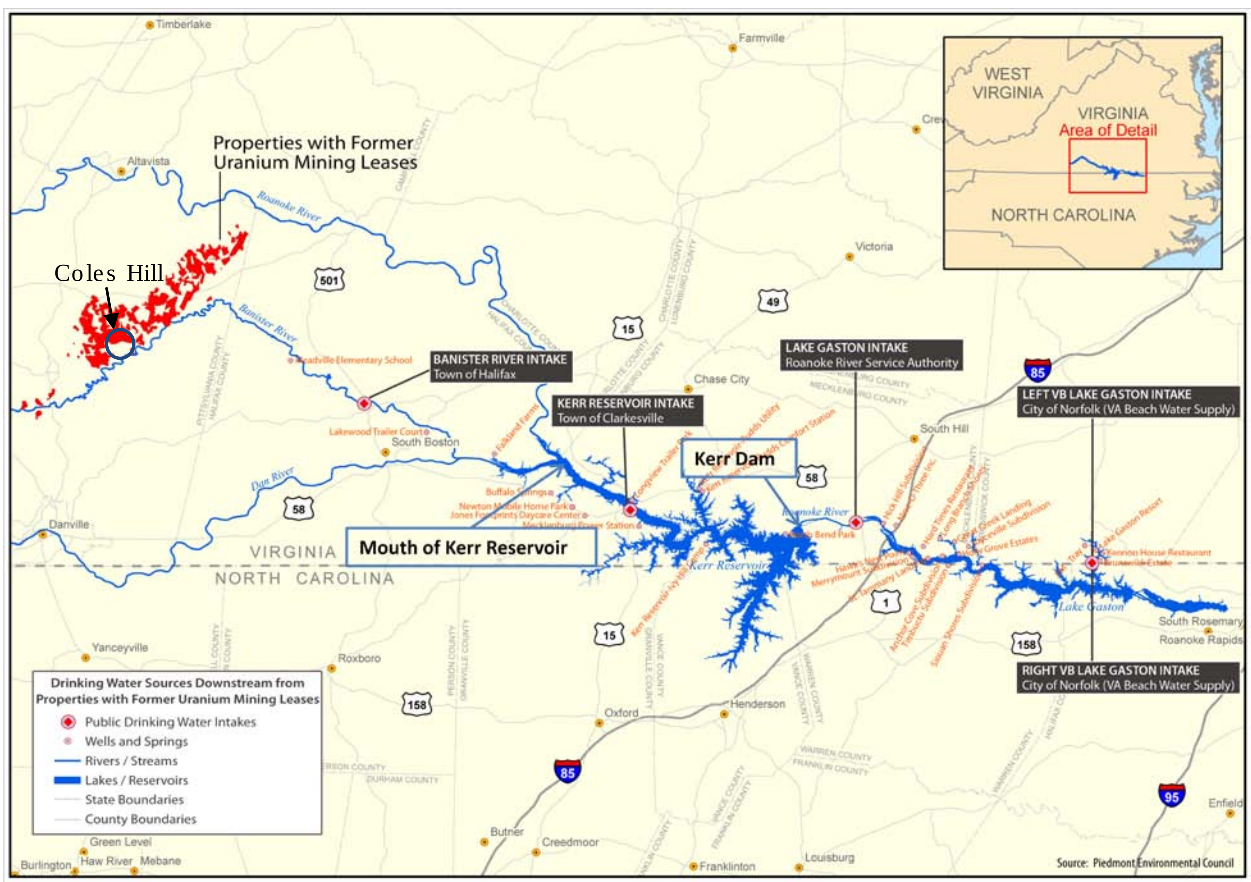

Figure ES-1. Location of Coles Hill Uranium Reserve in Virginia and Downstream Drinking Water Sources

Background

Mined uranium ore is normally processed by first grinding it to a small, uniform particle size (this is called the milling process) and then treating it with chemical solutions to extract the uranium. Because uranium ore is mostly present at relatively low concentrations in the United States (0.05 to 0.3 percent), uranium milling and extraction produces vast quantities of waste material known as tailings, which are typically stored in impoundments formed behind containment structures such as dams.

These tailings retain about 85 percent of the original radioactivity for hundreds of thousands of years because of other radioactive materials, such as radium and thorium, which are not extracted during the uranium milling process. These radioactive materials can adversely affect public health if they are not confined properly or are released to the environment. In addition, uranium tailings still contain uranium and other potentially hazardous substances such as arsenic, which are toxic and can affect public health if they leach into groundwater or surface water.

Historically, a number of tailings containment structures have failed in the United States and elsewhere, resulting in the release of radioactive (such as uranium tailings) and non-radioactive (such as coal ash, copper, iron, phosphate tailings) materials to downstream surface waters. Although there were a variety of reasons for these failures, such as seepage, structural defects, earthquakes, and foundation settlement, extreme precipitation events caused most of the failures world-wide, which, in many cases, led to loss of life and caused severe contamination downstream.

Climatic and geologic conditions surrounding uranium ore deposits in Pittsylvania County make the area prone to extreme rainfall events including tropical storms and hurricanes, some of which have generated substantial flooding. Although presently uranium tailings are required to be stored in specially designed waste disposal facilities called containment cells or structures in compliance with Nuclear Regulatory Commission regulations, there is concern that a failure of the uranium tailings containment structures could result in the contamination of the downstream drinking water supply sources along the Banister River, Roanoke River, Kerr Reservoir and Lake Gaston.

Preliminary Assessment Approach

In an effort to address this concern, a preliminary assessment was conducted to investigate potential impacts of uranium tailings discharged into Banister and Roanoke Rivers in case of catastrophic failure of a containment structure.

The preliminary assessment was based on a one-dimensional (1-D) numerical modeling/simulation of the Banister and Roanoke rivers and the Kerr Reservoir using the CCHE1D model developed by the University of Mississippi for the United States Department of Agriculture. CCHE1D is a software package that can simulate one-dimensional unsteady flows, sediment transport and streambed morphodynamics, and transport and fate of contaminants.

The framework employed for the preliminary assessment included simulation of the variation in radioactivity concentrations along Roanoke and Banister rivers and the Kerr Reservoir in case of catastrophic failure of a containment structure under sunny day and extreme flooding conditions throughout a period of one year each. Because the exact location of the potential mine, milling facility and the containment structures were not known at the time of this assessment, it was assumed that the containment structures could be located anywhere in the vicinity of Coles Hill and/or somewhere in the proximity of the area where former uranium leases were issued (as shown in Figure ES-1), within either the Banister River or Roanoke River watersheds.

Due to lack of site specific data associated with uranium milling, extraction, tailings properties and containment structure (location, volume, etc.), data from literature were used for various parameters needed for the simulations - such as the sediment concentration in tailings, particle size distribution, and radioactivity concentrations for radium-226 and thorium-230.

A range of values reported in the literature were used along with variables such as the volume of tailings and flood hydrographs to establish a range of possible scenarios that could potentially be implemented for this project:

- Volume of tailings – 0.8, 2.5, 5.0 and 8 million cubic meters (to account for storage volumes that can be achieved with a dam height of 5 m, 15 m, 30 m, and 50 m, respectively, and a surface area of 40 acres)

- Sediment concentration by weight of tailings – 15- (CSW1), 32.5- (CSW2), 50- (CSW3), and 70-percent (CSW4) as reported in literature

- Flood hydrographs – 10-percent (HYD1), 1-percent (HYD2), and 0.2-percent-annual-chance (HYD3) events (maximum discharges recorded by USGS gages in Banister and Roanoke rivers ranged between 58 and 94-percent of the 0.2-percent-annual-chance hydrographs) and an average water year hydrograph for the rivers

- Particle size distribution of tailings – two different particle size distributions reported in literature were used - one represents a wider grain size range and has a higher percentage of coarser sediments (GSC1) and the other has a narrower range of size classes and a higher percentage of finer sediments (GSC2).

- Radioactivity level and uranium content in tailings – minimum (RAD1) and maximum level (RAD2) radioactivity content due to radium-226 and thorium-230, and uranium content as reported in literature for the acid leaching process[1] (for three components of the tailings - sands, slimes and liquids)

The simulations were carried out to observe the movement of tailings and the variation of radionuclide concentrations in Banister and Roanoke rivers and Kerr Reservoir for a period of one to two years depending on the scenario. Tailings containment failure under sunny day (assumed dam failure without the effect of extreme floods) and extreme flooding (assumed dam failure as a result of an extreme rainfall event) conditions were simulated. For tailings containment failure scenarios under extreme flooding, percent chance hydrographs (which cause the dam failure) were appended by the average water year hydrograph.

[1] Radioactivity characteristics of uranium tailings exposed to alkaline leaching are less defined than acid leaching. Data reported for liquid and slime components of tailings fall within the limits used for this assessment for acid leaching.

Assessment Results

The preliminary assessment shows that radiological contaminants (radium-226 and thorium-230) in the water column and sediments in Banister and Roanoke rivers and the Kerr Reservoir could result in water column concentrations exceeding the regulatory maximum contaminant level[2] (MCL) for combined radium-226 and 228 in drinking water for an extended period of time. However, the radioactivity concentrations in the water column subsided after a certain period of time and fell below the MCL for combined radium by the end of simulations (which were run for approximately 364 days) as shown in Figure ES-2 and Table ES-1.

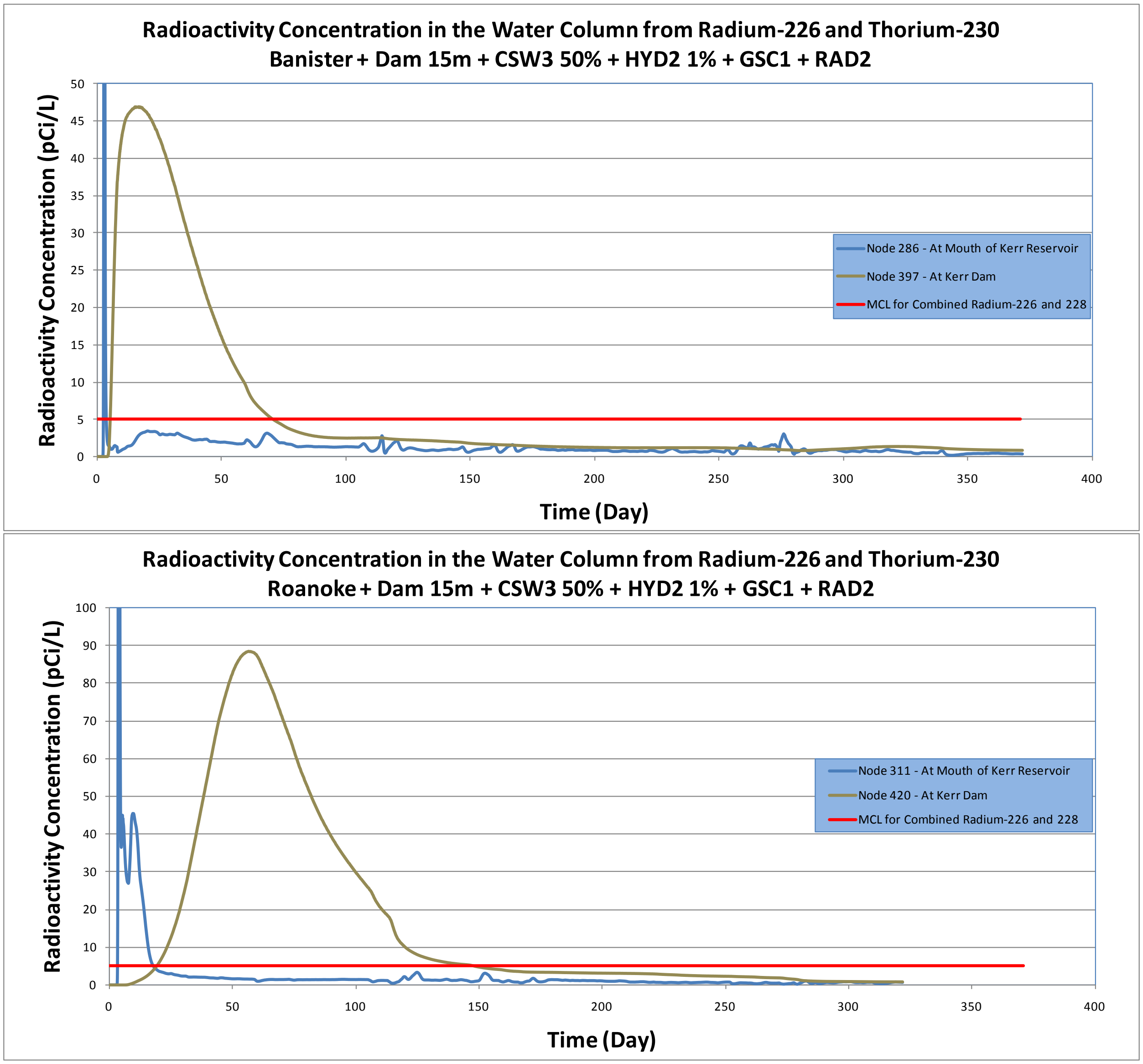

Figure ES-2. Variation in Radioactivity Concentration (dissolved and particulate) from Radium-226 and Thorium-230 in Banister and Roanoke Rivers for a Typical Scenario.

[2] There is no MCL for thorium; however, MCL for alpha/photon emitters is 15 pCi/L.

Table ES-1. Results Obtained for a Typical Scenario for Banister and Roanoke Rivers at Mouth of Kerr Reservoir and at Kerr Dam.

Long-Term Simulation Results (365 days) - Banister River CSW=50% - GSC1 - HYD2 (1%)							
Location	Dam Height (Represents Tailings Volume) (meters)	Initial Radioactivity Level of Tailings	Highest Concentration of Radioactivity in Water Column During Simulation (pCi/L)	Radioactivity Concentration in Water Column at End of Simulation (pCi/L)	Initial Radioactivity Level of Tailings	Highest Concentration of Radioactivity in Water Column During Simulation (pCi/L)	Radioactivity Concentration in Water Column at End of Simulation (pCi/L)
At Mouth of Kerr Reservoir	15	RAD1 (Min)	39	0.1	RAD2 (Max)	171	0.4
	30		81	0.2		383	0.6
At Kerr Dam	15		12	0.3		47	0.8
	30		24	0.5		101	1.6

Long-Term Simulation Results - Roanoke River CSW=50% - GSC1 - HYD2 (1%)							
Location	Dam Height (Represents Tailings Volume) (meters)	Initial Radioactivity Level of Tailings	Highest Concentration of Radioactivity in Water Column During Simulation (pCi/L)	Radioactivity Concentration in Water Column at End of Simulation (pCi/L)	Initial Radioactivity Level of Tailings	Highest Concentration of Radioactivity in Water Column During Simulation (pCi/L)	Radioactivity Concentration in Water Column at End of Simulation (pCi/L)
At Mouth of Kerr Reservoir	15	RAD1 (Min)	89	0.1	RAD2 (Max)	397	0.4
	30		150	0.3		711	0.8
At Kerr Dam	15		24	0.3		88	0.9
	30		39	0.5		153	1.7
MCL for Combined Radium-226 and 228 = 5 pCi/L							

It was also observed from the simulations that while the radioactivity concentrations in the water column diminish over time as river flow flushes the radionuclides from the system to Lake Gaston and further downstream, a significant amount of the radionuclides remain in the river/reservoir system adsorbed to the sand and slime components of the tailings that settle at the river bottom and in the reservoir. Table ES-2 shows how much of the initial radionuclides that entered each river as a result of tailings containment failure remain in the system after a one year of simulation for the same scenario provided in Table ES-1. As can be seen in Table ES-2, approximately 78 percent or more of the initial radioactivity released into the river/reservoir system still remains in the system and mostly in the sediments at the bottom of the river and in the reservoir after one year.

The radioactivity remaining in the sediments of bed layers will be prone to re-suspension multiple times over the years as large flows and extreme flood events are experienced by the rivers. To validate this phenomenon, a series of simulations were carried out in which a 1-percent annual chance hydrograph was imposed at the end of a sunny day failure scenario to evaluate the effect of an extreme flood on re-suspension of contaminated sediments. The results showed that the re-suspension of contaminated sediments from the river bed can cause radioactivity concentration levels to rise as shown in Figure ES-3. For example, simulations for Roanoke River revealed that radioactivity concentrations could increase by up to an order of magnitude that would be three times higher than the regulatory limit of 5 pCi/L.

Table ES-2. Radioactivity Remaining in the System for Banister and Roanoke Rivers for a Typical Scenario

	Units	Banister				Roanoke			
		DAM = 15m		DAM = 30m		DAM = 15m		DAM = 30m	
		RAD1	RAD2	RAD1	RAD2	RAD1	RAD2	RAD1	RAD2
Radioactivity Released from the Tailings Containment Failure	Ci	94	548	186	1086	91	533	183	1066
Radioactivity Out of the System at the end of Simulation	Ci	10	35	18	69	22	74	36	130
Radioactivity Remaining in the Water Column	Ci	0.3	0.8	0.5	1.5	0.3	1.9	0.5	1.7
Percent Radioactivity Remaining in the System	%	89	93	89	93	78	87	80	87

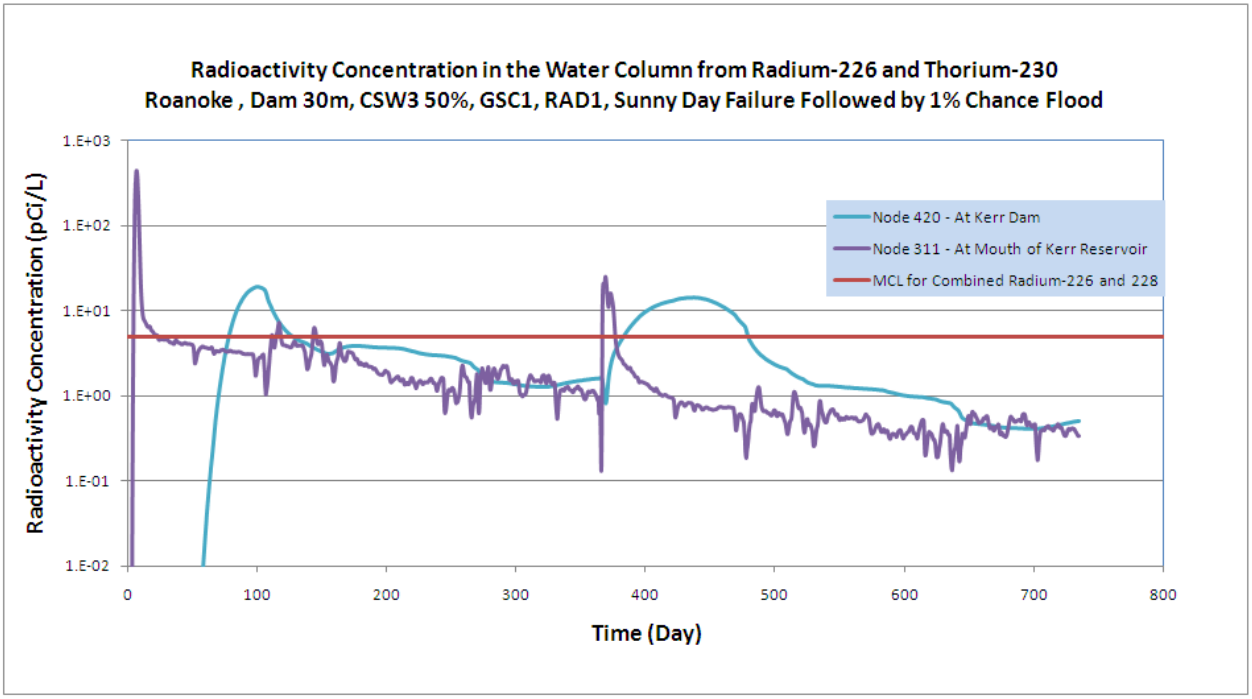

Figure ES-3. Variation in Radioactivity Concentration from Radium-226 and Thorium-230 as a Result of Re-Suspension of Contaminated Sediments

In addition to the radioactivity impacts of uranium tailings (due to radium and thorium) on the rivers and Kerr Reservoir, the transport and fate of uranium was also simulated since uranium is a toxic substance that can impact human health. The results show that uranium concentrations in the water may temporarily reach or exceed the regulatory limit of 30 µg/L throughout the river/reservoir system depending on its solubility as shown in Figure ES-4. Similar to radium and thorium, the majority of uranium in tailings settle in the bed sediments. Therefore, uranium-contaminated sediments will also be prone to resuspension multiple times over the years as discussed earlier in the case of radioactivity-contaminated sediments.

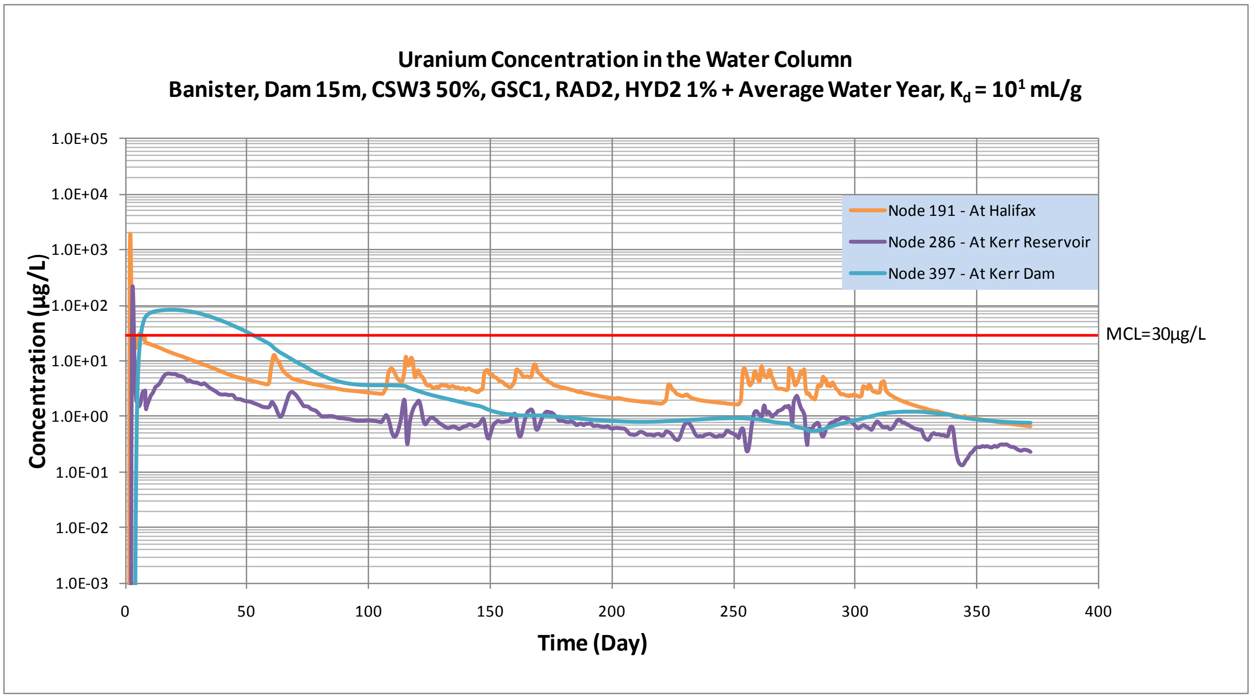

Figure ES-4. Variation in Uranium Concentration in Banister River for a Typical Scenario Using Soluble form of Uranium

Conclusions

Simulation results and conclusions derived as a result of the preliminary assessment were based on the best available information. These conclusions could be impacted depending on the variation in key parameters, such as the dam height for the uranium tailings containment structure, sediment concentration in the tailings, radioactivity level, uranium content, solubility characteristics of radiological elements and uranium, and the particle size distribution.

- A catastrophic failure of a uranium tailings containment structure could significantly increase radioactivity concentrations in the river/reservoir system and exceed the MCL established for radiological contaminants for drinking water for an extended period of time.
  - The MCL for gross alpha activity in Kerr Reservoir (water column) could be exceeded by an order of magnitude.
  - The gross alpha activity in Kerr Reservoir (water column) could remain above the MCL for several months or more after the failure.

- A significant amount of radioactivity remains in the river/reservoir system after a year following a catastrophic tailings dam failure.
  - The majority of radioactivity that enters the river/reservoir system as a result of a failure remains in bed sediments a year after the failure while dissolved and suspended radionuclides in the water column are flushed downstream.

  - Subsequent floods could re-suspend sediments and increase radioactivity concentration in the water column above the MCL established for radiological components for drinking water.

- Uranium concentrations in the water column may temporarily reach or exceed the MCL limit of 30 µg/L depending on its solubility.
  - Solubility of uranium appears to significantly affect its presence in the river/reservoir system. The more soluble the uranium, the faster it flushes out of the river/reservoir system to downstream water bodies. If the uranium is less soluble, the majority remains in the system deposited at the bottom of the river/reservoir system and can be re-suspended by subsequent floods.

- Reservoir operations (varying reservoir level to accommodate operational demands) may affect the arrival and residency time of radioactivity in Kerr Reservoir.
  - Length of radioactivity residence time in the reservoir depends on the inflows – higher flows flush radionuclides faster and reduce residence time; lower flows, on the other hand, increase residence time.