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An evaluation of health risk to the public as a consequence of in situ uranium mining in Wyoming, USA

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ABSTRACT

In the United States there is considerable public concern regarding the health effects of in situ recovery uranium mining. These concerns focus principally on exposure to contaminants mobilized in groundwater by the mining process. However, the risk arising as a result of mining must be viewed in light of the presence of naturally occurring uranium ore and other constituents which comprise a latent hazard. The United States Environmental Protection Agency recently proposed new guidelines for successful restoration of an in situ uranium mine by limiting concentrations of thirteen groundwater constituents: arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver, nitrate (as nitrogen), molybdenum, radium, total uranium, and gross α activity. We investigated the changes occurring to these constituents at an ISR uranium mine in Wyoming, USA by comparing groundwater quality at baseline measurement to that at stability (post-restoration) testing. Of the groundwater constituents considered, only uranium and radium-226 showed significant ($p < 0.05$) deviation from site-wide baseline conditions in matched-wells. Uranium concentrations increased by a factor of 5.6 (95% CI 3.6–8.9 times greater) while radium-226 decreased by a factor of about one half (95% CI 0.42–0.75 times less). Change in risk was calculated using the RESRAD (onsite) code for an individual exposed as a resident-farmer; total radiation dose to a resident farmer decreased from pre-to post-mining by about 5.2 mSv y^{-1}. Higher concentrations of uranium correspond to increased biomarkers of nephrotoxicity, however the clinical significance of this increase is unclear.

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1. Introduction

Approximately one eighth of the world's electricity (Nuclear Energy Institute, 2014) is supplied by 435 nuclear reactors (Nuclear Energy Agency and International Atomic Energy Agency, 2014). Over 58,000 tonnes of uranium ore were mined in 2014 to supply fuel for these reactors (Nuclear Energy Institute, 2014). In 2013, 47% of world-wide uranium production was the result of in situ recovery (ISR) mining. In the United States, the fraction of uranium production attributable to ISR is much higher (World Nuclear Association, 2015a, 2015b). Domestically, seven operational ISR mines produce 2300 tonnes of uranium per year, approximately 11% of domestic uranium consumption (United States Energy Information Administration, 2015), which powdered 100 reactors generating one fifth of the nation's electricity (Nuclear Energy Institute, 2014). ISR is the most economically efficient method of uranium extraction in the United States and an important generator of economic activity in rural parts of the country (e.g., Wyoming and South Dakota). However, there are risks associated with ISR uranium mining, most notably the contamination of a drinking-water aquifer with uranium or other heavy metals (United States Environmental Protection Agency, 2008).

The ISR process utilizes a series of injector and recovery wells to access, without excavation, below-ground uranium ore bodies. The chemistry of the ISR process varies with both geological and regulatory conditions. In the United States groundwater is pumped from recovery wells to the surface, where it is fortified with dissolved oxygen (or, less commonly hydrogen peroxide), carbon dioxide, and/or sodium bicarbonate, and then re-injected. Following each subsurface pass, the groundwater, now laden with uranium, is sent through ion-exchange resins for uranium recovery and re-fortified/rejuvenated. The circulation is a closed loop except for a small "bleed" (typically 0.5–1% of the total flow) maintained to prevent mine water from leaving the mining zone. When the ion exchange bed is filled to capacity with uranium, it is taken off-line and eluted; the resulting eluent is chemically treated to produce

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uranyl peroxide. A more detailed description of the ISR process can be found in Davis and Curtis (2007).

The ISR mining process may be conducted with either an acid or alkali agent. Currently, only the alkali process is used in the United States, although other countries such as Australia and Khazakstan employ acid leach processes. Here, we only consider the alkali processes as these are the techniques used at our field site.

The goal of this study was to quantify the risk resulting from changes in groundwater, induced by ISR at a uranium mine in Wyoming, USA. Our hypothesis was that post-restoration (stability) conditions on-site represent either (1) a significant increase in groundwater constituents beyond the range of conditions found naturally on-site prior to mining, and/or (2) a significant increase in risk to a resident farmer.

2. Material and methods

2.1. Description of site

The Smith Ranch-Highland ISR uranium mine is located in Converse County, Wyoming, USA (Fig. 1). The site is at 1500 m elevation and experiences a semi-arid climate, with an average annual temperature of 7 °C and average annual precipitation of 319 mm (National Oceanic and Atmospheric Administration, 2002). Wyoming is sparsely populated, with 584,000 inhabitants occupying 250,000 square kilometers, an area roughly the size of the United Kingdom. The dominant ground cover is mixed grass prairie (State of Wyoming, 2010). Pronghorn antelope (*Antilocapra americana*), mule deer (*Odocoileus hemionus*), white tailed deer (*Odocoileus virginianus*), and game birds such as wild turkey (*Meleagris gallopavo*), ducks, and Canadian geese (*Branta canadensis*), which are consumed by some local residents, are frequently found on-site.

Borch et al. (2012) provide a detailed description of subsurface conditions at Smith Ranch-Highland. Generally, uranium ore has been deposited in a sandy layer approximately 150–200 m belowground. The ore bearing sands are bounded above and below by shale deposits. Groundwater flow is estimated to be approximately 2–3 m per year. Uranium concentrations in ore body solids vary from a few hundredths of a percent to about one percent, with the bulk average typically being approximately 0.1%. Uranium ore deposits develop in permeable formations that are generally sandy. Borch et al. (2012) describe the hydrogeological processes that

Fig. 1. Map showing location of the Smith Ranch-Highland site and photograph depicting site landscape and a typical well-field.