SUPPLEMENTAL EXPERT OPINION REGARDING THE RENEWAL OF ISL URANIUM MININING (CROW BUTTE RESOURCES) NEAR CRAWFORD, NEBRASKA

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INTRODUCTION

Beginning in 2008 I have provided expert opinions to the Western Nebraska Resources Council and Owe Aku (among others) regarding Crow Butte Resources' ISL uranium mining near Crawford, Nebraska. Since that time, I have offered expert opinions on Crow Butte Resources' proposed expansions, and initiated or participated in several scientific studies intended to further clarify the issues I raised in those written opinions. I am offering this supplemental expert opinion in support of the Consolidated Interveners' new and revised contentions regarding the license renewal of the Crow Butte Resources ISL uranium mine near Crawford, Nebraska. I am concerned that issues regarding the lack of lixiviant containment raised in earlier opinions have not been addressed and also apply to the Consolidated Petitioners' contentions in this particular case. My goal in offering this expert opinion is not to protest uranium mining, but rather to express my concerns regarding threats to the region's diminishing water supplies and the future inhabitability of northwestern Nebraska and adjacent southwestern South Dakota. In this document I will briefly explain the basis for my concerns.

PROFESSIONAL BACKGROUND

I have 25 years' experience studying the geology of northwestern Nebraska and adjacent South Dakota. Following dissertation work on the regional geology from 1988-1995, from 1996-2006 I led teams of geologists from the Nebraska Geological Survey that mapped in detail the geology of most of northwestern Nebraska (a total of 80 1:24,000 quadrangles). The completion of this work frequently required detailed study of equivalent strata in adjacent Fall River, Shannon, and Todd counties in South Dakota. These maps, including digital versions (ArcInfo) and supporting field notes, are available from the University of Nebraska-Lincoln School of Natural Resources (contact Dr. Matthew Joeckel, Director). As a direct consequence of this mapping, I have published peer-reviewed articles on the Chadron Formation (Terry & LaGarry 1998), the Brule Formation (LaGarry 1998), the mapping of surficial deposits (Wysocki & others 2000, 2005), and local faults (Fielding & others 2007). From 2006-2008 I continued this work as an Adjunct Professor of Geology at Chadron State College (CSC) in Chadron, Nebraska. During this time I worked with and advised students studying the region's groundwater, surface water, and faults (Balmat & others 2008, Butterfield & others 2008). Since 2008 I have worked as an Instructor and Researcher in the Department of Math, Science, & Technology at Oglala Lakota College (OLC MST), serving the department as Co-Chair from 2009-2012 and Chair from 2012-2013. Since 2013 I have resumed my duties as a full-time instructor and researcher.

In addition to my ongoing geological work in Nebraska, I have been working with students and faculty to study the geology, groundwater, surface water, and heavy metal contaminants of southwestern South Dakota and the Pine Ridge Reservation. For the past 6 years our research has been funded by the National Science Foundation's Tribal Colleges and Universities Program

and Experimental Program for Stimulating Competitive Research, and the USDA National Institute for Food and Agriculture Tribal College Equity Program. We have formed and maintained partnerships with Chadron State College, the South Dakota Geological Survey, the South Dakota School of Mines and Technology, South Dakota State University, the University of Illinois Urbana-Champaign, the University of Illinois Center for Advanced Materials Purification of Water Systems, the Department of Health Physics at the University of Michigan School of Nuclear Engineering, the University of Washington Native American Research Center for Health, and the Technological University of Darmstadt, Germany. I have authored or co-authored reports detailing the preliminary results of studies describing toxic heavy metal contamination of drinking water (Salvatore & others 2010, Botzum & others 2011), characteristics of local aquifers (Gaddie & LaGarry 2010, LaGarry & others 2012), potential uranium contamination risk to communities on the Pine Ridge Reservation (LaGarry & Yellow Thunder 2012), and the transmission of uranium-contaminated water along regional faults (Bhattacharyya & others 2012).

THE CONCERNS

My concerns regarding the Crow Butte resources ISL uranium mine are the lack of confinement resulting from secondary porosity in the form of faults and joints, the problem of artesian flow, and the horizontal flow of water beyond the uranium-bearing strata. In my 2008 opinion on Crow Butte Resources' ISL mining I described in detail the stratigraphy of the region and potential contamination pathways, and established the plausibility of contaminants migrating away from the mine site into adjacent areas and aquifers. In this supplemental opinion I will concentrate on work that has been completed after 2008. It is beyond the scope of this opinion to review the entire scientific literature for the region, but I provide the most readily available recent research. Where appropriate, I also refer to Crow Butte Resources' FINAL ENVIRONMENTAL ASSESSMENT FOR THE LICENSE RENEWAL OF U.S. NUCLEAR REGULATORY COMMISSION LICENSE NO. SUA–1534.

The problem of secondary porosity

In order for ISL mining to be considered safe, the mined uranium-bearing strata must be isolated from rocks above and below by confining layers. Confining layers must be continuous, unfractured, and unperforated in order for containment to exist. There are three principal pathways through which contaminated water could migrate away from the uranium-bearing strata through adjacent confining layers (described in detail below): 1) secondary porosity in the form of joints and faults, 2) thinning or pinching out of confining layers, and 3) perforations made by improperly cased or capped wells. I will restrict my comments to situation (1), as situations (2) and (3) have been addressed in my earlier opinions and there is insufficient new data to warrant additional discussion.

Secondary porosity, in the form of intersecting faults and joints, is common in all of the rocks north, east, and south of the Black Hills Dome and along the Pine Ridge Escarpment (see Swinehart & others 1985). These faults and joints are generally oriented NW- SE and SW-NE, and are a result of the ongoing uplift of the Black Hills of southwestern South Dakota. Although many people consider the Black Hills uplift to have ended by the late Cretaceous Period (~65 Ma), the Black Hills were tectonically active in the late Eocene (Evans & Terry 1994), and continued to fault, fracture, and fold the rocks of northwestern Nebraska and southwestern South Dakota into the middle Miocene (Fielding & others 2007). Based on numerous small

earthquakes along the Sandoz Ranch-Whiteclay Fault, the area is tectonically active to this day (McMillan & others 2006). These earthquakes are relatively mild, and don't significantly damage surface infrastructure. However, even small earthquakes represent shifting and flexing of the earth's crust, and are continuously creating, closing, and redistributing the secondary porosity of the region's rocks and changing the flow pathways of the region's groundwater. This means that joints incapable of transmitting water one day may be able to transmit water at a later date. These faults and fractures transect all major bedrock units of the region. These faults connect the uranium-bearing strata to adjacent aquifers as well as modern river alluvium.

Preliminary studies of the interaction of these faults with surface waters in the region show that creeks that provide municipal water supplies can be entirely consumed and redirected by the region's secondary porosity. Chadron Creek, the stream that supplies water to the city of Chadron, Nebraska, went dry for the first time in the city's history. Subsequent study of the creek's water flow rates by Chadron State College students suggested that normal amounts of water are flowing from springs, but the water is disappearing into deeper alluvium or into fractures in the rock (Balmat & others 2008, Butterfield & others 2008). Following these observations, a Chadron State College graduate student studied the lineaments of northwestern Nebraska and southwestern South Dakota using data collected by high-flying aircraft, satellites, and the space shuttle, and showed that these represent widespread faults (Balmat & Leite 2008). Many of the faults in northwestern Nebraska and southwestern South Dakota persist for tens of miles (Diffendal 1994, Fielding & others 2007). Also, many of the ancient river deposits of the Tertiary strata, along with the alluvium deposited by modern rivers such as the Cheyenne River, the White River, and Hat Creek, follow fault zones because fractured rock erodes more easily.

Crow Butte Resources' license renewal application asserts that fault zones are known in the vicinity of the license area. The most notable of these is the White River Fault, which trends along the axis of the syncline in which the uranium-bearing Chamberlain Pass Formation (being mined for uranium in this case) was deposited (see LaGarry and LaGarry 1997, LaGarry 998). A review of the scientific literature shows that faults and joints are well known in rocks surrounding the Black Hills, and are known to interconnect major aquifers and the land surface (Swinehart & others 1985, Peters & others 1988, Fielding & others 2007). In earlier expert opinions, I described the extensive, detailed geologic mapping of the region conducted by the Nebraska Geological Survey (Table 1), and predicted that faults and joints would be capable of transmitting uranium-contaminated waters from depth onto the land surface. In 2012 my colleagues and I reported preliminary research showing uranium-contaminated artesian springs along the Sandoz Ranch-Whiteclay Fault in Fall River and Shannon counties (Bhattacharyya & others 2012), supporting those assertions. Based on the numerous studies reported here and the maps cited in Table 1, the absence of joints and faults in the vicinity of the proposed mine is a false perception, because joints and faults are ubiquitous in this region.

Despite being obvious when viewed from Earth's orbit (Balmat and Leite 2008), these joints and faults are difficult to observe when covered by Holocene surficial deposits. Crow Butte Resources' assertions that hydrologic modeling shows no evidence of faults is misleading, as it is possible to conduct such tests in ways that are unlikely to reveal the presence of a fault. In order to demonstrate a lack of containment, faults must be mapped and wells installed along them. Test wells can be configured to determine the hydrologic head along a fault relative to adjacent

strata, and measurements of water transmission capacity along faults can be made. Balmat and Leite (2008) and the "Whistleblower letter" (see my 2008 opinion) both reported faults intersecting the Crow Butte Resources mine license area (at about the location of the processing pland), and initial testing could be made there and preliminary measurements made. Additional faults could be tested in the vicinity of Red Cloud Buttes north of Crawford in the Smiley Canyon 1:24,000 Quadrangle and at in the Trunk Butte 1:24,000 quadrangle (Table 1). Joints are ubiquitous in the region, and many are available for testing.

It's worth noting that despite being made aware of this geological mapping and the published stratigraphic work that resulted from it, Crow Butte Resources continues to use outdated 1960's era concepts and nomenclature in their FINAL ENVIRONMENTAL ASSESSMENT FOR THE LICENSE RENEWAL OF U.S. NUCLEAR REGULATORY COMMISSION LICENSE NO. SUA–1534. They continue to refer to the uranium-bearing strata as "Basal Chadron Formation" rather than the currently used Chamberlain Pass Formation. If Crow Butte Resources is unable to follow easy to address simple scientific protocols such as using the currently accepted stratigraphic nomenclature, I am concerned about their diligence in addressing challenging issues such as the mapping of faults and joints. Reliance on outdated data, concepts, and assumptions about the geology of the region (including, but not limited to rocks folding, rather than fracturing) will make any and all modeling of the hydrology of the area meaningless.

Table 1. Open-file (OFM) maps from the Alliance 1:250,000 Quadrangle available from the Nebraska Geological Survey (University of Nebraska-Lincoln Conservation & Survey Division, School of Natural Resources). All maps are Nebraska quadrangles except as noted.

Map Name[1]	Date[2]	Map No.[3]	Authors
Sherrill Hills (WY-NE)	1997	53	LaGarry & LaGarry
Story	1997	54	LaGarry & LaGarry
Story NE	1997	55	LaGarry & LaGarry
Lone Tree Ranch	1997	56	LaGarry & LaGarry
Wayside	1997	57	LaGarry & LaGarry
Bohemian Creek	1997	58	LaGarry & LaGarry
Kirtley (WY-NE)	1997	59	LaGarry & LaGarry
Warbonnet Ranch	1997	60	LaGarry & LaGarry
Bodarc	1997	61	LaGarry & LaGarry
Five Points	1997	62	LaGarry & LaGarry
Whitney	1997	63	LaGarry, LaGarry, & Swinehart
Trunk Butte	1997	64	LaGarry, LaGarry, & Swinehart
Chadron West	1997	65	LaGarry, LaGarry, & Swinehart
Crawford	1998	66	LaGarry, Swinehart, & LaGarry
Crow Butte	1998	67	LaGarry, Swinehart, & LaGarry
Chimney Butte	1998	68	LaGarry, Swinehart, & LaGarry
Coffee Mill Butte	1998	69	LaGarry, Swinehart, & LaGarry
Dead Mans Creek	1998	70	LaGarry, Swinehart, & LaGarry
Belmont	1998	71	LaGarry, Swinehart, & LaGarry
Coffee Mill Butte SW	1998	72	LaGarry, Swinehart, & LaGarry
Coffee Mill Butte SE	1998	73	LaGarry, Swinehart, & LaGarry
Van Tassell (WY-NE)	1999	74	LaGarry, LaGarry, & Swinehart
Harrison West	1999	75	LaGarry, LaGarry, & Swinehart
Harrison East	1999	76	LaGarry, LaGarry, & Swinehart
Andrews	1999	77	LaGarry, LaGarry, & Swinehart
Smiley Canyon	1999	78	LaGarry, LaGarry, & Swinehart
Van Tassell SE (WY-NE)	1999	79	LaGarry, LaGarry, & Swinehart
Harrison SW	1999	80	LaGarry, LaGarry, & Swinehart
Harrison SW	1999	81	LaGarry, LaGarry, & Swinehart
Kyle Creek	1999	82	LaGarry, LaGarry, & Swinehart

Glen	1999	83	LaGarry, LaGarry, & Swinehart
Isinglass Buttes	2000	84	LaGarry, LaGarry, & Swinehart
Chadron NE	2000	85	LaGarry, LaGarry, & Swinehart
Chadron East	2000	86	LaGarry, Swinehart, & LaGarry
Bordeaux	2000	87	LaGarry, Swinehart, & LaGarry
Kings Canyon/Chadron 3 NW	2000	88	LaGarry, Swinehart, & LaGarry
Hay Springs Creek/Chadron 3 NE	2000	89	LaGarry, Swinehart, & LaGarry
Sand Canyon West/Chadron 3 SW	2000	90	LaGarry, Swinehart, & LaGarry
Sand Canyon East/Chadron 3 SE	2000	91	LaGarry, Swinehart, & LaGarry
Beaver Wall	2001	92	LaGarry, Swinehart, & LaGarry
Whiteclay	2001	93	LaGarry, Swinehart, & LaGarry
Whiteclay SW	2001	94	LaGarry, Swinehart, & LaGarry
Whiteclay SE	2001	95	LaGarry, Swinehart, & LaGarry
Hay Springs	2001	96	LaGarry, Swinehart, & LaGarry
Hay Springs NE	2001	97	LaGarry, Swinehart, & LaGarry
Hay Springs SW	2001	98	LaGarry, Swinehart, & LaGarry
Springs SE	2001	99	LaGarry, Swinehart, & LaGarry
Montrose	2001	108	LaGarry & LaGarry
Orella	2001	109	LaGarry & LaGarry
Wolf Butte	2001	110	LaGarry & LaGarry
Roundtop	2001	111	LaGarry, LaGarry, & Swinehart
Horn	2001	112	LaGarry & LaGarry
Clinton NW	2002	113	LaGarry, Swinehart, & LaGarry
Clinton NE	2002	114	LaGarry, Swinehart, & LaGarry
Clinton SW	2002	115	LaGarry, Swinehart, & LaGarry
Clinton	2002	116	LaGarry, Swinehart, & LaGarry
Rushville SE	2002	117	LaGarry, Swinehart, & LaGarry
Rushville SW	2002	118	LaGarry, Swinehart, & LaGarry
Rushville NE	2002	119	LaGarry, Swinehart, & LaGarry
Rushville	2002	120	LaGarry, Swinehart, & LaGarry
Gordon NW	2003	121	LaGarry, Swinehart, & LaGarry
Hog Island	2003	122	LaGarry, Swinehart, & LaGarry
Gordon	2003	123	LaGarry, Swinehart, & LaGarry
Gordon SE	2003	124	LaGarry, Swinehart, & LaGarry
South of Gordon	2003	125	LaGarry, Swinehart, & LaGarry
Coburn Canyon	2003	126	LaGarry, Swinehart, & LaGarry
Bovee Valley West/Rushville 3 SW	2003	127	LaGarry, Swinehart, & LaGarry
Bovee Valley East/Rushville 3 SE	2003	128	LaGarry, Swinehart, & LaGarry
Whistle Creek NW	2004	129	LaGarry, Swinehart, & LaGarry
Whistle Creek NE	2004	130	LaGarry, Swinehart, & LaGarry
Marsland NW	2004	131	LaGarry, Swinehart, & LaGarry
Marsland	2004	132	LaGarry, Swinehart, & LaGarry
Box Butte Reservoir West	2004	133	LaGarry, Swinehart, & LaGarry
Box Butte Reservoir East	2004	134	LaGarry, Swinehart, & LaGarry
Box Butte NW	2005	137	LaGarry, Swinehart, & LaGarry
Box Butte NE	2005	138	LaGarry, Swinehart, & LaGarry
Skunk Lake NW	2005	139	LaGarry, Swinehart, & LaGarry
Skunk Lake NE	2005	140	LaGarry, Swinehart, & LaGarry
Smith Lake	2005	141	LaGarry, Swinehart, & LaGarry
Twin Lakes NE	2005	142	LaGarry, Swinehart, & LaGarry
Dolly Warden Lake	2005	143	LaGarry, Swinehart, & LaGarry
Billys Lake	2005	144	LaGarry, Swinehart, & LaGarry

Notes for Table 1:

1. **Where two names are given, the former name is listed first, and the current name second**
2. **Date indicates when map went on open file.**
3. **Numbers were assigned by the Conservation & Survey Division**

The problem of artesian flow

Artesian flow occurs when there is a hydrologic connection, through faults or highly permeable strata, between groundwater sources high on the landscape and the land surface lower down. The weight of water in overlying strata exerts pressure downward into water within the uranium-bearing strata, which can then be released as artesian water flow (like a fountain) where the topographically lower uranium-bearing strata is exposed at the surface, or where it is punctured by drilling. Artesian flow was observed by Crow Butte Resources and was acknowledged in their FINAL ENVIRONMENTAL ASSESSMENT FOR THE LICENSE RENEWAL OF U.S. NUCLEAR REGULATORY COMMISSION LICENSE NO. SUA–1534. Artesian flow is most likely where the upper confining layer is perforated by secondary porosity (faults and joints), poorly constructed or improperly sealed exploration wells, or thinning or absence of upper confining layers. Artesian flow could transmit lixiviant, the most toxic mineral-laden of waters, onto the land surface (and into White River alluvium) and discharge large amounts of contaminants into connected aquifers or faults in a very short time.

The problem of horizontal flow

Confining layers above and below uranium-bearing strata limit the unwanted spread of contaminants from an ISL site. However, horizontal flows within the uranium-bearing strata and along intersecting faults and joints are also of concern. Such flow can rapidly redirect lixiviant or mine waste away from the mine site and into unexpected breaches in the confining layers. In my 2008 opinion I cited research on the transmission of water along secondary porosity (faults and joints) in the Brule Formation of up to 1500 feet/day. I also provide detailed, plausible conditions under which this contamination could spread to adjacent aquifers. Crow Butte acknowledges such secondary porosity in the Brule Formation (but not the faults that create it) in their FINAL ENVIRONMENTAL ASSESSMENT FOR THE LICENSE RENEWAL OF U.S. NUCLEAR REGULATORY COMMISSION LICENSE NO. SUA–1534. This acknowledged secondary porosity, if breached by unconfined lixiviant, would transmit contaminants to the major, mapped faults north of the Pine Ridge in Nebraska in only a few years, and from there into adjacent regions.

CONCLUDING REMARKS

Based on the arguments presented above, it is my expert opinion that ISL mining in the area surrounding Crawford, Nebraska cannot be adequately contained. Reports of artesian flow, the acknowledged and prevalent jointing and faulting leading to widespread secondary porosity, along with potentially high horizontal flow through regional faults indicate that during the course of its operation the Crow Butte Resources ISL uranium mine will most likely contaminate the region with unconfined lixiviant. This contamination will pollute and render unusable ground and surface water southwards into Nebraska and surface waters within the White River drainage northeastwards into greater South Dakota. Also, based on my reading of Crow Butte Resources' FINAL ENVIRONMENTAL ASSESSMENT FOR THE LICENSE RENEWAL OF U.S. NUCLEAR REGULATORY COMMISSION LICENSE NO. SUA–1534, no comprehensive review of the geologic literature was conducted despite my criticisms on that issue in the 2008 opinion. In my view, the use of outdated scientific literature, or in this case, a general lack of review of recent study, should not be seen as an opportunity to operate in a knowledge vacuum. Much of the Great Plains region was studied prior to the 1980's and the general acceptance of Plate Tectonics Theory, and therefore generally misrepresents the geologic setting of the region. This was true

of the geologic literature used to justify ISL mining near Crawford, Nebraska, and is also true of the data used to justify proposed mining near Edgemont, South Dakota. Crow Butte Resources' complete and continued reliance of modeling based on outdated and incomplete parameters will never be sufficient to satisfy concerns based on actual mapping and recent published studies. It is incumbent upon potential ISL operators, as it is with any natural resource extractors, to seek out the most recent research and expert opinions on the geological settings in which they propose to operate.

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