APPENDIX D5:
GEOLOGY

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D5 GEOLOGY

The discussions of geology and seismicity related to the proposed Reno Creek Project (Proposed Project) are contained in this section. Detailed information about the Proposed Project area and its immediate surroundings is provided to the extent that AUC is permitted to acquire such data under 10 CFR Part 40.32(e) and the regulations of the State of Wyoming.

A discussion of the Production Zone Aquifer (PZA) and the mudstone units providing geologic confinement above and below the PZA is found in Section D5.2 of this chapter. The PZA is an Eocene-age sandstone formation which hosts the uranium mineralization for the Proposed Project. There is continuous geologic confinement of the PZA over the entire Proposed Project area. As a consequence, ISR operations in the PZA can be conducted without significant potential impacts to groundwater resources.

D5.1 Regional Setting

The Proposed Project is located in the Pumpkin Buttes Uranium District in the central Powder River Basin (PRB) of northeast Wyoming as shown in Figure D5A-1 in Addendum D5-A. Outcrop geology of the district is also depicted on Figure D5A-1.

Active uranium projects in the Pumpkin Buttes District are depicted on the map including Reno Creek (AUC LLC), Moore Ranch, Willow Creek (Uranium One), and Uranerz' Hank Unit and Nichols Ranch projects. Willow Creek is currently producing uranium using ISR methods.

According to NUREG-1910 (GEIS Section 3.3.3), the PRB encompasses an area of about 31,000 km^2 (12,000 mi^2) in Campbell, Johnson, and Converse counties within the Eastern Wyoming Uranium District. The first uranium discoveries in the PRB near Pumpkin Buttes were in 1951 (Davis, 1969). Other uranium deposits were found along a 60 miles northwest-southeast trend in the southwest portion of the PRB. Production began in 1953.

D5.1.1 Structural Geology

The PRB extends over much of northeastern Wyoming and southeastern Montana, and consists of a large north-northwest trending asymmetric syncline depicted in Figure D5A-2, Structure Map, showing contours on the top of the Fox Hills Sandstone which lies at approximately 6,500 feet in depth in the Proposed Project area (Figures D5A-3 and D5A-4). The basement axis lies near the western edge of the basin, and the present surface axis lies to the east of the basement axis near the Pumpkin Buttes approximately 10 miles west of the Proposed Project. The basin is bounded by the Big Horn Mountains to the west, the Black Hills to the east, and the Hartville Uplift and Laramie Mountains to the south.

The PRB is filled with sediments of marine and continental origin ranging in age from early Paleozoic through Cenozoic as shown in Figure D5A-3. Sediments reach a maximum thickness of about 20,000 feet in the deepest parts of the basin. The top of the Precambrian is projected to be 17,500 feet deep in the Proposed Project area.

Figure D5A-4 is an oil and gas log (Yates Petroleum, API # 49-005-45589) located immediately to the north of the Proposed Project area in Section 19, T43N, R73W. The total depth of the well is 10,690 feet. The location of the well is shown on Figure D5A-5, a location map for oil and gas (non CBM) tests in and adjacent to the Proposed Project.

During Paleozoic time most of northeastern Wyoming lay beneath shallow marine waters on the continental shelf. Throughout this time, gentle subsidence of the shelf and intermittent uplifts were accompanied by the deposition of marine limestone, shale and sandstone.

Periods of oceanic regression and transgression began in the region during the late Paleozoic and increased in the Mesozoic. These cycles resulted in the deposition of layers of marine sand and carbonates interbedded with coarse-grained, non-marine clastic sediments.

Following a long period of stability during the Mesozoic, tectonic forces of late Paleocene to early Eocene ushered in mountain building events related to the Laramide orogeny. Uplift began to affect the western continental margin and modify the landscape of central and eastern Wyoming (Seeland, 1988). As a result of these tectonic forces, the PRB was the site of active subsidence surrounded by orogenic uplifts (Big Horn Mountains, Laramie Mountains, Black Hills, etc). The Tullock Member of the Fort Union marks the first evidence of basin downwarp and synorogenic filling (outcrop geology shown on Figure D5A-1).

Throughout the Paleocene, uplift of the Big Horn Mountains, Laramie Mountains and Black Hills continued on the margins of the PRB. Erosion of these highlands produced clastic material which now constitutes the upper members of the Fort Union Formation in the basin's flood plain. Thick sequences of mudstone in the Lebo Shale Member around the margins of the basin indicate a typical Laramide depositional environment. The Laramide orogeny was near its peak activity in Tongue River time as indicated by a marked increase in the deposition of coarse sandstones. A period of deformation and erosion accompanied by westward tilting of the basin preceded a final Laramide surge and deposited the clastic rocks of the Eocene Wasatch Formation, the uranium-bearing

host rock in the Proposed Project. The Wasatch dips northwestward at approximately one degree to two and a half degrees in this portion of the PRB (Sharp et al., 1964).
During the Oligocene, regional volcanism to the west of the basin resulted in the deposition of tuffaceous claystone, sandstone and conglomerate of the White River Formation. Downwarping of the basin was completed in early Cenozoic time and subsidence of the enclosing mountain ranges after deposition of the White River Formation caused local tilting of these and older beds toward the mountains. Remnants of the White River Formation overlie the Wasatch Formation in the center of the Pumpkin Buttes District (Figure D5A-1).

Throughout the Miocene, most of Wyoming was an upland over which windblown sands were deposited. Erosion prevailed throughout most of the region during the Pliocene but locally tuffaceous clay and fresh water limestone were deposited in low lying, regional lakes.

In the late Pliocene the region again underwent uplift and, since the Pleistocene the area has been undergoing erosion. Most of the White River Formation and much of the Wasatch Formation have been removed. Remnants of the White River conglomerate resisted erosion to form the mesa caps of the Pumpkin Buttes. Concurrently, upper Cenozoic and Quaternary gravels were deposited on terraces, flood plains and valley floors. More recently, Holocene alluvium has filled channels eroded in the older rocks and windblown sand has formed dunes, predominantly in the southwest corner of the basin.

D5.1.2 Regional Stratigraphy

Outcrops of post-marine formations in the southern part of the basin consist of the Lance, Fort Union, Wasatch and White River Formations (Figures D5A-1, D5A-3, and D5A-4). The Upper Cretaceous Lance Formation is the oldest of these units, and consists of 1,000 to 3,000 feet of thinly-bedded, brown to gray sandstones and shales. The upper part contains minor, dark carbonaceous shales and thin coal seams, indicating a changing depositional environment over time.

The Paleocene Fort Union Formation conformably overlies the Lance and consists of continental and shallow non-marine deposits in two members. The lower member consists of fine-grained, clay-rich, drab to pink sandstone, with minor claystone and coal. The sandstones were deposited as alluvial fans and braided stream channels during erosion of the uplifted Black Hills, Bighorn, and Laramie Mountains. The upper member consists of shale, clayey sandstone, fine-to-coarse-grained sandstone, and some extensive sub bituminous coal beds. The total thickness of the Fort Union Formation varies between 2,000 and 3,500 feet (Sharp et al., 1964).

The Fort Union Formation is the water source for the City of Wright, located approximately 10 miles east of the Proposed Project. Due to its position (up dip) of the Proposed Project, the PZA (the host for uranium mineralization) is eroded away and is not present in the Wright area.

The early Eocene Wasatch Formation unconformably overlies the Fort Union Formation around the margins of the basin. However, the two formations are conformable and gradational towards the basin center and the Proposed Project area. The relative amount of coarse, permeable clastics increases near the top of the Fort Union, and the overlying Wasatch Formation contains numerous beds of sandstone which are sometimes correlatable over wide areas. Except in isolated areas of the PRB, the Wasatch-Fort Union contact is generally set at the top of the thicker coals or of some thick sequence of clays and silts. The Badger Coal is regarded as the approximate formation boundary in the Proposed Project area.

The Wasatch Formation crops out at the surface in the Proposed Project area. The Wasatch is similar to the Fort Union, but also contains thick lenses of coarse, crossbedded, arkosic sands deposited in a high-energy fluvial environment. The Wasatch Formation reaches a maximum thickness of approximately 500 to 700 feet within the Proposed Project area.

Remnants of the Oligocene White River Formation crop out on the Pumpkin Buttes, located approximately 10 miles to the west-northwest of the Proposed Project area. Virtually all of the White River has otherwise been eroded away. The youngest sediments consist of Quaternary alluvial sands and gravels locally present principally in drainages.

The central part of the PRB contains at least 10,000 feet of sediments underlying the Upper Cretaceous Lance Formation. Most of the rocks are marine shales and mudstones. Notable sandstones below the Lance are found in the Cretaceous Fox Hills Sandstone (transitional marine to non-marine), and the Teckla, Teapot, and Parkman members of the Mesa Verde Formation (Figure D5A-3 and D5A-4). The Tekla and Teapot Sandstones are approximately 7,060 to 7,800 feet below land surface in the Proposed Project area, and are sandstones currently employed in the Basin for disposal of ISR liquid 11e.(2) byproduct through Class I UIC injection wells.

The Upper Cretaceous Tekla and Teapot Sandstone members of the Mesa Verde Formation lie approximately 7,060 to 7,800 feet below the PZA. AUC has applied for Class I UIC Permits from the WDEQ to inject liquid 11e.(2) byproduct into the Tekla and Teapot Sandstones as part of the Proposed Project.

Potential oil and gas targets in this portion of the PRB and near the Project include the Parkman Sandstone, Niobrara Shale, Turner Sandstone, and Mowry Shale. These deeper Cretaceous oil and gas targets below the Mesa Verde Formation and to the Turner Sandstone are shown on Figure D5A-4 include the Niobrara Shale and the Turner Sandstone. These formations occur over 2,000 feet deeper than the potential deep disposal zones. The great presence of low-permeability shale units overlying and underlying the potential disposal zones effectively isolate the units from sandstones higher and lower in the geologic section.

The Madison limestone and Tensleep sandstone are approximately 15,000 feet below the land surface (Figure D5A-3) and approximately 7,000 to 8,000 feet below the Teckla and Teapot and Sandstones.

D5.2 Site Geology

Discussions of local geologic conditions present at the site are included in the following sections.

D5.2.1 Structure

The Proposed Project area lies within a portion of the PRB that generally dips to the northwest at approximately one degree (Figure D5A-2). Based on historic and recent geophysical and lithologic logs covering an area of more than 50 square-miles, including the Proposed Project area, mineralized host sandstone exhibits a dip ranging from 35 to 60 feet per mile.

A structure map (Figure D5A-6) drawn on the base of the Lower Felix Coal shows the local dip at the Proposed Project. The Upper and Lower Felix Coals occur within a mudstone unit immediately above the PZA and are locally continuous, making them excellent correlation markers in the Proposed Project area. As shown in Figure D5A-6, dips are gentle and do not suggest the presence of faults. Faulting has not been detected across the entirety of the Proposed Project area.

D5.2.2 Stratigraphy

As noted in NUREG-1910 (GEIS Section 3.3.3), the primary hosts for uranium mineralization at the Proposed Project area are sandstones of the lower Wasatch Formation of Eocene age (49 to 54.8 million years). The formation consists of interbedded, arkosic sandstone, conglomerate, siltstone, mudstone and carbonaceous shale, all compacted but poorly cemented (Harshman, 1968).

The upper Wasatch has been largely eroded away in the Proposed Project area. The Wasatch Formation is a fluvial sedimentary sequence deposited during a period of wet, subtropical climatic conditions (Seeland, 1988). Laramide tectonic forces uplifted highlands to the south and southwest that provided sediments which were transported northward by rivers flowing into the PRB. Sands deposited by meandering streams formed channel and point bar deposits that typically fine upwards through the sequence. In addition to the fluvial sands, claystones, siltstones, carbonaceous shale, and thin coal seams were deposited in overbank environments. Fine grained sediments were deposited as levees, splays, and in backwater swamps adjacent to sands deposited by higher energy fluvial environments.

The Wasatch Formation occurs at the surface in the Proposed Project area, except where it is occasionally covered by recent alluvium in shallow drainages. The generally accepted base of the Wasatch in the Proposed Project area is the top of the Badger Coal, located approximately 250 feet below the sandstone horizon proposed for uranium recovery operations.

Unconformably underlying the Wasatch is the Paleocene age Fort Union Formation. The Paleocene Fort Union Formation is composed of continental and shallow non-marine deposits associated with Laramie uplift and basin filling. Thicknesses noted by Hodson (1973) are approximately 2,300 feet in the eastern basin, 2,900 feet in the southwest, and almost 3,500 feet in the northwest part. The Fort Union is a heterogeneous unit of fine-grained sandstones, interbedded shales, carbonaceous shale and coal. The formation thickens to the southwest and is conformably underlain by the Lance Formation and unconformably overlain by the Eocene-age Wasatch Formation. Outcrops of the Fort Union Formation encircle most of the basin and beds dip basinward.

The Fort Union Formation is the major source of coal in the PRB and also hosts significant volumes of exploitable coal bed methane (CBM) reserves. The largest coal mines in the United States are located along the north-south trending outcrop of the Fort Union approximately eight-miles east of Wright, Wyoming, and extending north to the Gillette, Wyoming area. The mines produce coal from the Anderson/Big George coal seams that reach thicknesses of over 100 feet.

The CBM production that is present in parts of the Proposed Project area is from the Anderson/Big George Coal, at approximately 1,000 to 1,100 feet below ground surface. The coal seams occur approximately 600 feet below the base of the PZA, the sandstone unit proposed for uranium ISR operations. This depth relationship is illustrated on the Deep Oil and Gas Type Log (Figure D5A-4).

Research by the Wyoming State Geological Survey (Clarey, 2009) has shown that the CBM production in the Anderson/Big George has had no measurable effect on water levels in any Wasatch aquifer. More details about the relationship of CBM production and potential uranium production are found in Appendix D-6 (Water Resources).

The All Night Creek (ANC) well cluster was installed by the US Bureau of Land Management (BLM) to assess the effects of CBM dewatering activity in Section 36, Township 43N, Range 74 West, in the western portion of the Proposed Project area (Appendix D6-B, Figure D6B-11, ANCVSS is within the well cluster, west side of map). Water levels in the well cluster were gauged for over 10 years providing an excellent historical record. Water level data from the ANC cluster regarding dewatering of the Big George Coal were used in the Clarey report.

The deepest well in the BLM's ANC cluster was completed in the Big George Coal at approximately 1,070 feet. After approximately six years of CBM dewatering activity in the area the well went dry in 2007, and has stayed dry to the present time. Other wells in the cluster were completed in shallower sandstone units including the Proposed Project's Production Zone Aquifer, and Overlying Aquifer. During the period from 2002 through the present, water levels in the Production Zone Aquifer and the Overlying Aquifer were unaffected by pumping (Appendix D6-B, Figures D6B-55 through D6B-57) indicating that CBM dewatering will not impact AUC's ISR operations.

AUC contacted the BLM in 2010 and was granted access to the ANC wells for water level monitoring points during pump testing of AUC's PZM5, located approximately 4,000 feet to the east-southeast of the ANC cluster. Water levels in the ANC well cluster were unaffected by the PZM5 hydrologic test (Figure D6B-46), further evidence that CBM and ISR operations can coexist without adverse effects.

D5.2.2.1 Hydrostratigraphic Units

Units immediately underlying the mineralized host sandstone, the host sandstone, and units overlying the host sandstone are discussed in the following section.

Geophysical logs representative of various portions of the Proposed Project area are found as Figures D5A-7 through D5A-10. A geological cross section index map (Figure D5A-11) and five cross sections (Figures D5A-12 through D5A-16) are also included to provide several views over the entire length and breadth of the Proposed Project. A second set of cross sections are provided to show more detail regarding each of the ore body areas (Figures D5A-17 through D5A-23). The individual geophysical logs and cross sections demonstrate the continuity of the PZA and the over and underlying confining aquitards.

The following summary provides the stratigraphic nomenclature and acronyms with descending depth utilized for the Proposed Project for the units of interest present in the Wasatch Formation:

- SM Unit (SM wells): Shallow water table unit present in some locations. Based on geologic and hydrologic data, this unit does not meet the requirements of an aquifer in the Proposed Project area;
- Overlying Aquifer (OM wells): Overlying aquifer relative to the production zone. This aquifer also represents the uppermost aquifer observed in the Proposed Project area;
- Overlying Aquitard (OA): Confining unit providing isolation between the production zone and overlying aquifer;
- Production Zone Aquifer (PZA);
- Underlying Aquitard (UA): Confining unit providing isolation between the production zone and underlying unit; and
- Underlying Unit (UM wells): Discontinuous underlying sand units relative to the production zone. Based on geologic and hydrologic data, this unit does not meet the requirements of an aquifer in the Proposed Project area.

In the Proposed Project area, the lower-most unit of the Wasatch Formation comprises the UA Aquitard which lies below the PZA and above the Badger Coal. The aquitard, which includes the underlying unit, is approximately 200 to 250 feet thick and consists of a laterally continuous sequence of undifferentiated mudstones and clays, with discontinuous and often lenticular sandstones. This confining unit is present under the entire Proposed Project area.. An isopach map of the UA Aquitard is included (Figure D5A-24).

The first significant sandstone in closest proximity (subjacent) to the Production Zone Aquifer (PZA) is designated as the Underlying Unit. As depicted on the cross sections in Addendum D5-A, the Underlying Unit is not an aquifer or a continuous, correlatable zone.

The mineralized host sandstone, or PZA, overlies the UA Aquitard. The PZA is a discrete and laterally continuous sandstone ranging from under 75 feet to approximately 220 feet thick as shown in Figure D5A-25. In the central portion of the Proposed Project area, the PZA is divided into an upper sandstone and a lower sandstone by a five to 30 foot thick mudstone. This division occurs locally in other portions of the project as well, and multiple mudstone lenses of limited lateral extent are commonly observed throughout the Proposed Project area. In areas where the PZA is bifurcated mineralization can be found both above and below the mudstone lens.

At various localities within the Proposed Project area all horizons from the base to the top of the host sandstone can be favorable for uranium deposition. However, economically significant uranium mineralization occurs most frequently in the lower half of the PZA.

In the far eastern portion of the Proposed Project area the PZA is partially saturated, and in limited areas uranium mineralization is present above the potentiometric surface of the PZA. Based on recent work by AUC, the mineralization in the uppermost, unsaturated portion of the PZA does not represent a significant percentage of the overall uranium resource. As work on the project progresses this saturated/partially saturated relationship to mineralization will be examined in detail.

Sandstones within the PZA that host the uranium mineralization are commonly crossbedded, graded sequences fining upward from very coarse at the base to fine grained at the top, representing sedimentary cycles from five to twenty feet thick. Stacking of depositional cycles has resulted in sand body accumulations over 200 feet thick.

The unit overlying the PZA in the Proposed Project area is the Overlying (OA) Aquitard. Figure D5A-26, an isopach map of the unit, addresses the thickness of the zone from the top of the PZA to the first significant overlying sandstone. The unit consists of a laterally continuous sequence of silt and clay rich mudstones, thin coal seams, and discontinuous sandstones. The thickness of the OA Aquitard can change rapidly due to discontinuities in the overlying sandstone units contained within this portion of the section, but is present as a continuous confining unit across the entire Proposed Project area.

The Felix Coal seams form a laterally continuous marker bed within the lower part of the OA Aquitard. In the eastern portion of the Proposed Project area, there are Upper and Lower Felix Coal seams, separated by approximately five feet of mudstone. The Upper Felix Coal seam pinches out or climbs in the section in the western portion of the Proposed Project area, causing a correlation break from east to west. The Felix Coal seams range from five to 10 feet in thickness. A structure map drawn on the base of the Lower Felix Coal is shown in Figure D5A-6. Minor structural undulations are indicated by the mapping, but generally the dip is consistent and no faulting is evident.

The Felix coals are not CBM production targets in the Proposed Project area. The closest permits for possible usage of the Felix seam for CBM production is approximately 20 to 25 miles north of the Proposed Project area.

The first significant sandstone above the Felix Coal is designated as the Overlying Aquifer. Generally the sandstones comprising Overlying Aquifer are discontinuous, difficult to correlate over distances exceeding a few thousand feet, and are contained within mudstones of the OA Aquitard. This conceptual depositional relationship is depicted on cross sections in Addendum D5-A. In the central portion of the Proposed

Project area the sandstone is well developed and attains a thickness of approximately 90 feet near the PZM4 well cluster.

A discontinuous, water table zone, referred to as the SM Unit, has also been identified by drilling at four of the well cluster locations. To determine if a water table zone is present at the well clusters, test borings were air-drilled to a depth of approximately 70 feet. Two-inch I.D. slotted PVC casing was temporarily installed for observation of groundwater infiltration. If a minimum of five feet of water was observed after standing a few days the temporary well was recompleted as a permanent monitoring well. The shallowest water level in the SM Unit was approximately 35 feet below ground surface.

Three of the seven SM tests proved to be dry, and the four that were converted to wells are poor producers. The term SM Unit has been used to describe the shallow water bearing zones as they do not fit the definition of aquifers. A discussion of this definition can be found in Section D6.2.3 of Water Resources.

The above data demonstrate that the PZA is geologically confined across the entire area of the Proposed Project, and that only the Overlying Aquifer exhibits characteristics of an aquifer. All other water bearing units outside of the PZA are not classed as aquifers.

Figures D5A-7 through D5A-10 are typical geophysical logs RC0005 (West), RC0004 (Central), RC0003 (Southeast), and RC0001 (East) that illustrate characteristics of the various units across the Proposed Project area.

As outlined in the above discussion, stratigraphic continuity of the OA Aquitard (including the Felix Coal seams), the PZA, and the UA Aquitard has been demonstrated by drilling and mapping of the units across the five mile length of the Proposed Project area.

D5.2.3 Lithologic Characteristics

Lithologic data at the Proposed Project is extensive. Records from historic and recent drilling include descriptions of samples and geophysical logs from thousands of drill holes beginning with exploration drilling in the late 1960s.

Drilling a total of 807 plug holes, well pilot holes, and core holes has been conducted by AUC since August 2010. Cuttings samples were collected at five-foot continuous intervals for lithologic descriptions by AUC geologists from surface to total depth. A collection of cuttings samples have been saved for future reference. The new drilling has been incorporated into AUC's extensive database of historic log data providing thousands of geologic data points in the Proposed Project area. New and historical drill holes are shown in Addendum RP-A (Plug and Abandonment Plan) in the Reclamation Plan.

A deep stratigraphic test hole penetrating the total thickness of the Wasatch Formation through the Badger Coal marker at the top of the Fort Union Formation, was drilled in each of AUC's seven well clusters. The stratigraphic hole was the first hole drilled in each cluster in order to provide lithologic and stratigraphic information for use in determining completion depths of each of the various wells in the group. Three additional stratigraphic test holes to the Badger Coal were drilled in the southwestern portion of the Proposed Project area to provide more detailed sub regional control.

AUC recovered core samples from the Overlying and Underlying Aquitards and the Overlying Aquifer in the PZM4 Well Cluster, and from the PZA in the west (Section 36, T43N, R74W) and southwest (Section 6, T42N, R73W) portions of the Proposed Project area. Cores from the multiple zones were recovered to evaluate characteristics of each of the lithologic units, and were obtained from 10 separate core hole locations during the past year. Figures RP.**A**-1 through RP.A-3 in Addendum RP-A in the Reclamation Plan illustrate the locations of the core holes.

Cores were collected for multiple purposes and analyses as follows:

1) Visual inspection and lithologic logging of sandstones, mudstones, and the Felix Coal seams;
2) Vertical and horizontal permeability and porosity analyses by various methods in major lithlogic units including aquitards (claystones, mudstones, siltstones), unmineralized sandstones, and mineralized sandstones;
3) Effective Porosity;
4) Bulk density;
5) Grain size analysis;
6) Clay content and mineralogy;
7) PZA sandstone lithology, mineralogy, and petrology;
8) Uranium mineral(s) identification; and
9) Metallurgical testing by bottle roll and column leach using varied oxidants and lixiviant strengths. Testing will provide data regarding amenability of uranium leaching and insights regarding geochemistry at the Proposed Project.

Results are complete for the first six items listed above, and are summarized on Tables D5A-1 through D5A-4 in Addendum D5-A. The last three items listed above are detailed in Addendum D5-C.

Work completed in regard to items 7 and 8 was by the Colorado School of Mines (CSM). AUC provided a mineralized core sample from core hole RC0008C, located in Section 36, Township 43 North, Range 74 West, to the QEMSCAN facility of CSM in Golden, Colorado for analysis. Results were received in a report dated May 1, 2012 titled "SIP

Development and QEMSCAN Test Analyses of U Bearing Samples". The report is included in Addendum D5-C. For clarification, SIP is Species Identification Protocol, and QEMSCAN is the acronym for Quantitative Evaluation of Minerals by Scanning Electron Microscopy. Two samples were analyzed from core provided from 378.5 to 380 feet in depth. The material was classified as arkosic sandstone, consisting primarily of quartz and feldspar in a clayey matrix. Coffinite, uraninite, and pitchblende were the uranium minerals identified. The CSM analyses support the lithologic and mineralogical characteristics reported in core and cuttings examinations and historical data originally generated by Rocky Mountain Energy.

Metallurgical testing was conducted using varied oxidants and lixiviant strengths employing bottle roll and column leach methods. Results were favorable and indicate that leaching can be conducted using oxygenated sodium bicarbonate lixiviants.

General conclusions regarding lithologic characteristics of the major units can also be made on the basis of recent core and cuttings examinations and historical data originally generated by Rocky Mountain Energy.

The three lithologies encountered most commonly at the Proposed Project are mudstones, sandstones and coal (lignite). A thin veneer of soil is developed at the ground surface due to weathering of the lithologic units of the Wasatch Formation.

Mudstone is the term used for silt and clay dominated sediments at the Proposed Project. Very fine grained sands are also found within these low-energy depositional sequences. Depending on clay and silt content these units can range from siltstones to claystones. Mudstones closely adjacent to the Felix Coal seams often have the visual appearance of true claystones. Petrographic studies, clay analysis, and grain size distribution analyses are underway and/or planned to more definitively determine the type and percentage of sediments comprising the mudstone sequences.

As observed in core, mudstone units are often dark to medium gray, thinly laminated, and occasionally contain carbonaceous material. Carbonaceous clayey units grading to lignites adjacent to the Felix Coal seams have been observed in core. Increasing clay content often imparts a dense waxy appearance in zones with very low visual permeability.

Sandstones at the Proposed Project are described as arkosic and/or feldspathic in composition. Sands range from very fine to very coarse grained. Occasional pebble size clasts are also present. Colors range from light gray to dark gray in unoxidized areas, and yellowish gray (limonitic) to pink (hematitic) in oxidized areas. Cores often exhibit low angle cross bedding, but can be massive with only minor visible bedding planes. Fining upward sequences are often observed within depositional sequences. Accessory minerals include pyrite (trace to five percent) and calcium carbonate that form isolated hard lenses up to ten feet thick. Carbonaceous material is occasionally present in reduced portions of the sandstone. Grains have undergone considerable transport and range in appearance from sub angular to well rounded. Sorting ranges from good to poor with interstitial clay and/or silt forming a less permeable matrix in isolated areas.

D5.2.4 Permeability and Porosity Measurements

Core samples from the PZM4 Well Cluster were collected for analysis of permeability and porosity (P&P) from the Overlying Aquifer, Overlying Aquitard, and Underlying Aquitard. Additional core samples from wide spaced core holes in the southwest portion of the Proposed Project area (RC0001C, 2C, 6C, 7C, and 9C) were recovered for analysis of properties of the PZA.

Permeability, porosity, and measurements of other rock properties were conducted by Core Laboratories and Weatherford Laboratories. Results are found in Tables D5A-1 through D5A-3.

<u>Overlying Aquifer</u>

Klinkenberg air permeability results from the Overlying Aquifer (two horizontal, one vertical) ranged from 1376 to 1775 md. Porosity measurements ranged from 35.65 percent to 40.63 percent.

<u>Production Zone Aquifer</u>

Klinkenberg air permeability results from the PZA sandstone (five horizontal, one vertical) ranged from 1073 to 3121 md. Porosity measurements ranged from 32.30 percent to 34.43 percent.

Klinkenberg air permeability results from the PZA cemented by calcium carbonate (one horizontal, one vertical) ranged from .178 to 2022 md (2022 md is a high, questionable result apparently due to a fractured core plug). Porosity measurements ranged from 12.67 percent to 15.07 percent, consistent with the observed tight, highly cemented condition.

One analysis of effective porosity was made on a PZA sandstone sample from core hole RC0007C. In this case the Klinkenberg permeability was 1801 md, the non-effective porosity was 31.8 percent; however the effective porosity measurement of this sample was 23.7 percent. Effective porosity excludes porosity related to bound water in clays resulting in a lower number.

Underlying Aquitard

Klinkenberg air permeability results from the Underlying Aquitard mudstone (two vertical) ranged from 5.2 to 10.1 md. Porosity measurements ranged from 21.95 percent to 29.92 percent.

This same Underlying Aquitard interval was also tested using a liquid permeability test (cap rock analysis) by Core Laboratory. In this case the vertical permeability result was 0.000584 md, a much lower result due to the method used. Liquid permeability measurement methods are regarded as a much more appropriate method for this type of analysis; therefore while the air permeability results of 5.2 to 10.1 md are useful in a qualititative sense, AUC regards the 0.000584 md liquid permeability result to be the accurate measurement. Pump test results also confirm that the aquitard is a very effective non-leaky hydrostratigraphic unit.

Overlying Aquitard

The Overlying Aquitard was also tested using a liquid permeability test (cap rock analysis) by Core Laboratory. The vertical permeability result was 0.0005877 md, very low and similar to the result from the Underlying Aquitard.

Based on these data, permeability and porosity of the PZA appears to be favorable for ISR operations. Liquid vertical permeability tests performed on core from Overlying and Underlying Aquitards indicated they exhibit highly impermeable, favorable conditions for confinement of fluids within the PZA.

D5.2.5 Mineralogy

Sandstones at the Proposed Project are described as arkosic and/or feldspathic in composition. Quartz grains are a major component with moderate amounts of potassium and calcium feldspars. Accessory minerals include pyrite (less than five percent)) and calcium carbonate cement. Carbonaceous material is occasionally present in reduced portions of the sandstone.

Recent whole rock mineralogy work by AUC and reports from analytical work by Rocky Mountain Energy in the late 1970s indicate that quartz ranges from 50 to 60 percent, feldspars comprise approximately 20 to 25 percent, and clays are present as smectite, kaolinite, and illite may comprise up to 20 percent of the total.

AUC has collected core for submission for analytical work to determine the uranium mineralogy. Analyses of core from mineralized sandstones will be conducted to determine the type of uranium minerals present at the Proposed Project. In addition

AUC will test for any associated elements that may be present such as vanadium to provide a basic understanding of the geochemistry of the deposit.

As noted in NUREG-1910 (GEIS Section 2.1), the main ore minerals in the unoxidized zone are coffinite and pitchblende (a variety of uraninite). Low concentrations of vanadium (~100 ppm) are sometimes associated with the uranium deposits at the Proposed Project, based on metallurgical testing conducted by AUC. Of five recently tested core samples, only one exhibited molybdenum (0.6 mg/kg) Also, selenium was only detected in one sample at 6.9 mg/kg. Arsenic was detected in all samples ranging from 1.4 to 14 mg/kg. Scattered lenses of calcium carbonate cement occur throughout the area, but only rarely contain anomalous uranium.

AUC will verify past work and will have petrographic work conducted to more accurately determine the composition of the host sandstones, siltstones, and claystones.

D5.2.6 Uranium Mineralization

Uranium deposits accumulated along roll-fronts (also referred to as redox fronts) at the down-gradient terminations of oxidation tongues within the PZA sandstone and are stratabound and genetically related to geochemical interfaces. The oxidation tongues are extensive, covering square miles down dip of oxidized outcrops. Ore grade concentrations occur on the reduced side of the geochemical interface.

The Eocene Wasatch Formation is approximately 500 to 700 feet thick in the Proposed Project area. Uranium mineralization is confined to the host sandstone of the Production Zone Aquifer (PZA). The PZA occasionally contains significant mudstone sequences with varying silt and clay content. Uranium deposits are found within a sand unit ranging from 50 to 200 feet in thickness, and at depths ranging from 170 to 450 feet below ground surface.

Uranium intercepts are variable in thickness ranging from one foot to over 40 feet thick. Thin low grade residual upper and lower limbs of the roll fronts often occur in reduced mudstones that form upper and lower boundaries of oxidized sand units.

The uranium mineralization occurs as coatings on sand grains within the host sandstone aquifer. Dissolved uranium carried in groundwater precipitated as groundwater flowed laterally (downgradient) through the redox boundary. The maximum dimensions of the ore bodies are at the leading edge of the solution-front where the alteration tongue protrudes down gradient of the original depositing groundwater flow direction (Anderson, 1969).

While in solution, uranium is readily transported and remains mobile as long as the oxidizing potential of the groundwater is not depleted. When the dissolved uranium encounters a reducing environment it is precipitated and deposited at the interface between the oxidizing and reducing environments known as the redox front. The redox front will progress down gradient as new influxes of oxidizing groundwater redissolve and transport uranium. Although groundwater flow through porous sands can be in the range of a few feet per day, progression of the redox front is several magnitudes slower.

Alteration or oxidation of the PZA sandstone in the Reno Creek area was produced by the down-gradient movement of oxidizing, uranium bearing groundwater solutions. Uranium mineralization was precipitated by reducing agents and carbonaceous materials in the gray, reduced sands. The host sandstones, where altered, exhibit hematitic (pink, light red, brownish-red, orange-red) and limonitic (yellow, yellowish-orange, yellowish-brown, reddish-orange) alteration colors which are easily distinguished from the unaltered medium-bluish gray sands. Feldspar alteration, which gives a “bleached” appearance to the sands from the chemical alteration of feldspars into clay minerals, is also present. Limonitic alteration dominates near the “nose” of the roll fronts. The remote barren interior portions of the altered sands are usually pinkish-red in color. The uranium mineralization is contained in typical Wyoming roll-front deposits that are highly sinuous in map view. A diagram of a roll front using electric logs from the southwest portion of the Proposed Project area is included as Figure D5A-27.

Carbon trash is occasionally present in both the altered and reduced sands. In general, the unaltered sands have a greater percentage of organic carbon (~0.2 percent) than the altered sands (0.13 percent) in selected cores (historical data) analyzed. Carbon in unaltered sands is shiny; while it is dull and flaky in the altered sands.

D5.2.7 History of Uranium Exploration and Development

Initially, Rocky Mountain Energy (RME) and subsequently Energy Fuels Nuclear, Inc. (EFN) and its successor International Uranium Corporation (IUC) performed exploratory drilling in the general Reno Creek area from 1968 through 1994, including more than 4,000 drill holes. In the mid 1970’s RME formed a joint venture with Mono Power and Halliburton Company to develop the property for mining. The joint venture applied for and received a research and development (R&D) Pilot Plant license in 1978 from the NRC and DEQ. RME tested two injection/recovery patterns under the license.

Pilot Test Pattern 1 incorporated the use of an acid lixiviant. However, it was determined in pilot scale testing that severe permeability reduction caused a loss of injectivity and production, resulting in the test’s early termination. The cause of permeability loss was the result of high levels of calcium mobilized by the acid and precipitating as gypsum within the void spaces of the target sand, thus sealing off the formation Restoration and stabilization of the groundwater of Pattern I was acknowledged and signed off by the NRC in March of 1986 (Accession #8604040293/Docket #04008697).

Subsequently, RME conducted a second test (Pattern 2) using a carbonate lixiviant. This model consisted of six monitor wells, four injection wells, and two production wells. Pattern 2's testing objectives were: to develop a successful and efficient system for commercial development, confirm the effectiveness of the carbonate lixiviant, and to substantiate groundwater restoration according to Wyoming DEQ standards. The Pattern 2 ISR pilot test was successful, showing both good recovery and a lack of permeability lost. Test production was terminated in 1980, and restoration was started Pattern 2 pilot testing culminated in regulatory signoff in June 1983 with the approval of carbonate leaching for commercial operations at Reno Creek under Materials License Number SUA-1338 as part of NRC Docket #04008797/Accession #8309220119.

The Reno Creek Pattern 2 restoration report can be viewed in Addendum OP-A in the Operations Plan. This addendum provides more detail regarding the historical in-situ recovery operations of RME Research and Development (R&D) and restoration efforts in the Proposed Project area.

RME also conducted a large scale Hydrogeologic Integrity Test during 1982. The investigation had two objectives:

- Determine if historical exploration holes drilled prior to the enactment of drill hole abandonment regulations had naturally sealed themselves; and
- Determine if there is hydraulic communication between the PZA sandstones and the Overlying Aquifer using a series of pump tests in the PZA.

The tests of historical drill hole plugging involved re-entering 33 abandoned drill holes to check conditions and plugs caused by swelling of naturally occurring mudstone layers. In addition, twenty-four monitoring/test wells were constructed, of which 18 were pump and/or injection-tested. The Hydrogeologic Integrity Test report can be found in Addendum D6-E.

During re-entry of the old holes, obstructions were generally encountered at each of the mudstone horizons present from water table to the base of the PZA. An inflatable packer was set above each of these obstruction horizons as encountered and pressure-tested to see what hydrostatic pressure the obstruction could withstand. The obstructions in the mudstone units referred to herein as the Overlying Aquitard (lying above, between, and below the Felix Coal seams) consistently withheld surface gauge hydrostatic pressures of 120 to 150 psi without bleeding off. Clays in the Overlying Aquitard were recognized at the time to be of a swelling variety, contributing to the natural sealing observed by RME.

Beginning in 1980, all drill hole abandonment incorporated plugging of drill holes with bentonite or other approved plugging material in accordance with WDEQ regulations. The current plug and abandonment practices can be found in Addendum RP-A of the Reclamation Plan.

RME's pump testing showed that there was no measurable communication between the PZA and the Overlying Aquifer. Full details concerning the pump testing and the hydrologic characteristics of the PZA are described in Section D6.2.6.

EFN/IUC acquired the Reno Creek project from RME and submitted its applications to NRC for a commercial source materials license and to WDEQ for a Permit to Mine. Changing economic conditions caused IUC to withdraw its application in 1999, and ultimately the mining claims and fee mineral leases were dropped. Strathmore Minerals Corporation re-staked mining claims starting in 2004 and operated the project via AUC LLC. Bayswater Uranium Corporation and Pacific Road Resources Funds jointly acquired AUC LLC in 2010.

D5.3 Drill Holes

The Reno Creek Project area was extensively explored from the late 1960s through 1991 by Union Pacific Railroad and its subsidiaries Rocky Mountain Energy (RME) and Union Pacific Resources. Energy Fuels Nuclear (later International Uranium Corporation, IUC) and Power Resources (PRI) acquired the properties and drilled an additional 300 to 400 holes in the 1990's and early 2000's time frame. Known drill holes locations are tabulated and depicted in Addendum RP-A (Plug and Abandonment Plan) in the Reclamation Plan.

Additionally, American Nuclear (ANC) and Tennessee Valley Authority (TVA) explored the southwest portion of the Proposed Project area during approximately the same time period that Rocky Mountain Energy was active in the area. ANC and TVA drilled approximately 695 holes in the general area on properties adjacent to RME's holdings.

AUC's properties span the former holdings several of the former operators, and include approximately 2,665 historical drill holes and plugged wells within the Proposed Project boundary. An additional 215 holes lie within the 0.5 mile drill hole review area (2,880 holes total). Approximately 100 of the holes were cased wells that were plugged and abandoned by previous operators.

AUC LLC drilled 807 holes from 2010 through 2012, 45 of which are cased wells that will remain in place for an unknown period of years for groundwater monitoring purposes.

The 762 holes that are not cased wells were plugged and abandoned in accordance with WDEQ/LQD Chapter 8 and per the WDEQ approved "AUC LLC Reno Creek Project Drilling Notification 401 Permit Amendment 2, TFN 5 6/175" dated February 9, 2011. AUC's Plug and Abandonment Plan can be found in Addendum RP-A of the Reclamation Plan.

All future exploration and delineation plug holes will be capped, sealed or plugged in accordance with WDEQ/LQD Non-Coal Rules and Regulations Chapter 8 "Exploration by Drilling" as amended. The plugging procedure is outlined in Section 2 of Chapter 8 and requires an approved grout be emplaced in the drill hole from the bottom of the hole to within five feet of the ground surface. Grout means sealant material that is stable, has low permeability and possesses minimum shrinking properties such that it is an optimal sealing material for well plugging and drill hole abandonment. Following the installation of the grout, the drill hole shall be backfilled to the surface with dry non-slurry materials or capped with a concrete cap set at least two feet below the ground surface and then backfilled to the surface with native earthen materials to ensure the safety of people, livestock, wildlife, and machinery in the area.

During the past year 12 historic holes were found in the southwest portion of the project area. The holes were surveyed and found to match coordinate locations of ANC/TVA drill holes. AUC opened the holes to total depth, ran geophysical logs and plugged with high solids bentonite grout per the procedure described above. AUC proposes to use a similar procedure for plugging other historic drill holes at the site as follows:

- A search for old holes will be conducted in the southwest portion of the site where drilling was conducted by ANC and TVA in mineralized areas. AUC currently has no electric logs for the ANC or TVA holes so AUC will gain value by opening the holes to total depth, examining the type of plugging that currently exists (natural or otherwise), and probing the holes with down hole geophysical logging equipment. Once logged, the holes will be plugged using standard procedures described above;
- In other areas of the project where AUC possesses historic electric logs, AUC will be prepared to search for, and plug old drill holes in proximity to future production units if pump testing and hydrologic results indicate that leakage through old drill holes might be a problem. Holes will be plugged as described above;
- Integrity testing by Rocky Mountain Energy (Hydrogeologic Integrity Evaluation, 1982 Addendum D6-D) indicated that old drill holes have been sealed by either natural swelling clays or by plug gel which was in use following regulatory requirements after approximately 1980. The integrity testing provides a strong indication that re-plugging of old drill holes may not be necessary; and

- AUC will plug any old open holes that may be encountered while working anywhere within the Proposed Project area.

In addition to uranium exploration logs, CBM drilling logs are publicly available and have been examined and correlated across the Proposed Project area. The US Bureau of Land Management completed a cluster of wells in the southwest portion of the project area, and logs and water level data from the wells has been incorporated into AUC's database. The wells were completed in the Big George Coal horizon and four sandstone aquifers above the Big George as reported by the Wyoming State Geological Survey (Clarey, 2009).

Historically, common practice in the Pumpkin Buttes Uranium District was to drill bore holes using 4¾ to 5¼ -inch diameter bits by conventional rotary drill rigs circulating drilling mud. The cuttings were typically collected over five-foot intervals and laid out on the ground in rows of 20 samples (100 feet) by the driller. The site geologist examined the cuttings in the field to determine lithology and geochemical alteration. AUC continues this practice for current drilling.

Upon completion of the drilling, the bore holes were logged, from the bottom of the hole upward, with a gamma-ray, self-potential, and resistance probe by either a contract logging company or possibly a company-owned logging truck. Down-hole drift surveys were also conducted in many of the historical drill holes.

All of AUC's bore holes were logged by an independent down-hole geophysical contractor, Century Geophysical Corporation, immediately after the holes were drilled. Current electric logging generally records data for gamma ray, SP, resistance, neutron and deviation (drift). Lithologic and geophysical logs are stored electronically and on hard copy by AUC for future use.

The Drill Hole Plug and Abandonment Plan in Addendum RP-A of the Reclamation Plan lists all drill holes known to AUC in the Proposed Project area and ½ mile buffer.

D5.4 Seismology

The discussion of seismology within the Proposed Project and surrounding areas includes: an analysis of historic seismicity, a deterministic analysis of nearby faults, an analysis of the maximum credible "floating earthquake," and a discussion of the existing short- and long-term probabilistic seismic hazard analysis. Intensity values and descriptions can be found in Tables D5B-1 and D5B-2 in Addendum D5-B.

D5.4.1 Seismic Hazard Review

The seismic hazard review was based on analysis of available literature and historical seismicity for the Proposed Project area. Appendix A to 10 CFR Part 40 presents criteria relating to the operation of conventional uranium mills and the disposition of tailings or wastes. Criterion 4 of that Appendix lists site and design criteria that must be adhered to whether tailings or wastes are disposed of above or below grade. Because there will be no mill or tailings impoundment at the Proposed Project, AUC contends that Criterion 4 design criteria are not necessary for either of the previously mentioned structures to support this application. Criterion 4(e) deals with seismic hazards and states that, "The impoundment may not be located near a capable fault that could cause a maximum credible earthquake larger than that which the impoundment could reasonably be expected to withstand. As used in this criterion, the term ‘capable fault’ has the same meaning as defined in section III (g) of Appendix A of 10 CFR Part 100. The term ‘maximum credible earthquake’ means that earthquake which would cause the maximum vibratory ground motion based upon an evaluation of earthquake potential considering the regional and local geology and seismology and specific characteristics of local subsurface material." There are no capable faults (i.e., active faults) with surface expression mapped within or near the Proposed Project area, according to the USGS (2009a).

D5.4.2 Seismicity

The following discussion of seismicity in Wyoming and the Proposed Project area is based primarily on Wyoming State Geological Survey Information Pamphlet 6 (Case and Green 2000), Seismological Characterization.

D5.4.2.1 <u>Historic Seismicity Near the Proposed Project Area</u>

Historic seismic events for Campbell County and other counties surrounding the Proposed Project area including Natrona, Converse, and Johnson Counties are summarized below.

<u>Campbell County</u>

Five magnitude 2.5 and greater earthquakes have been recorded in Campbell County. The first earthquake recorded in the county occurred on May 11, 1967. This magnitude 4.8 earthquake was centered in southwestern Campbell County approximately seven miles west-northwest of Pine Tree Junction. The second event took place on February 18, 1972, when a magnitude 4.3 earthquake occurred approximately 18 miles east of Gillette. No damage was reported for either event.

Two earthquakes were recorded in Campbell County during the 1980s. On May 29, 1984, a magnitude 5.0, intensity V earthquake occurred approximately 24 miles west-southwest of Gillette. The earthquake was felt in Gillette, Sheridan, Buffalo, Casper, Douglas, Thermopolis, and Sundance. On October 29, 1984, a magnitude 2.5 earthquake occurred approximately 25 miles west-northwest of Gillette. No damage was reported. Most recently, on February 24, 1993, a magnitude 3.6 earthquake occurred in southeastern Campbell County approximately 10 miles east-southeast of Reno Junction. No damage was reported.

Natrona County

Twelve magnitude 2.5 or intensity III and greater earthquakes have been recorded in Natrona County. The first earthquake that occurred in Natrona County took place on December 10, 1873, approximately two miles south of Powder River. People in the area reported feeling the earthquake as an intensity III event. Two of the earliest recorded earthquakes in Wyoming occurred near Casper. On June 25, 1894, an estimated intensity V earthquake was reported approximately three miles southwest of Evansville. Residents on Casper Mountain reported that dishes rattled to the floor and people were thrown from their beds. Water in the Platte River changed from fairly clear to reddish, and became thick with mud due to the riverbanks slumping into the river during the earthquake (Mokler, 1923). An even larger earthquake was felt in the same area on November 14, 1897. This intensity VI-VII earthquake, one of the largest recorded in central and eastern Wyoming caused considerable damage to a few buildings. On October 25, 1922, an intensity IV-V earthquake was detected approximately six miles north northeast of Barr Nunn. The event was felt in Casper; at Salt Creek, 50-miles north of Casper; and at Bucknum, 22 miles west of Casper. No significant damage was reported at Casper.

One of the first earthquakes recorded near Midwest occurred on December 11, 1942. The intensity IV-V event occurred approximately 14 miles south of Midwest. Although no damage was reported, the event was felt in Casper, Salt Creek, and Glenrock. On August 27, 1948, another intensity IV earthquake was detected approximately 6 miles north-northeast of Bar Nunn. No damage was reported.

In the 1950’s, two earthquakes caused some concern among Casper residents. On January 23, 1954, an intensity IV earthquake occurred approximately seven miles northeast of Alcova. No damage was reported. On August 19, 1959, an intensity IV earthquake was recorded north of Casper, approximately six miles north-northeast of Bar Nunn. People in Casper reported feeling this event. However, it is uncertain if this earthquake actually occurred in the Casper area, as it coincides with the Hebgen Lake, Montana, earthquakes that initiated on August 17, 1959.

Only one earthquake was reported in Natrona County in the 1960s. On January 8, 1968, a magnitude 3.8 earthquake occurred approximately 10 miles north-northwest of Alcova. No damage was reported.

An earthquake of no specific magnitude or intensity occurred approximately 13-miles southeast of Ervay on June 16, 1973. No one felt this earthquake and no damage was reported.

No other earthquakes occurred in Natrona County until March 9, 1993, when a magnitude 3.2 earthquake was recorded 17-miles west of Midwest. No damage was reported. A magnitude 3.1 earthquake also occurred in the far northwestern corner of the county on November 9, 1999. No one reported feeling this earthquake that was centered approximately 32 miles northwest of Waltman.

Most recently, on February 1, 2003, a magnitude 3.7 earthquake occurred approximately 16-miles north-northeast of Casper. Numerous Casper residents felt this event.

Converse County

Twelve magnitude 3.0 and greater earthquakes have been recorded in Converse County. These earthquakes are discussed below. The first earthquake recorded in Converse County occurred on April 14, 1947. The earthquake had an intensity of V, and was felt near LaPrele Creek southwest of Douglas.

On August 21, 1952, an intensity IV earthquake occurrred approximately seven miles north-northeast of Esterbrook in Converse County. It was felt by several people in the area, and was reportedly felt 40 miles to the southwest of Esterbrook. Three additional earthquakes have occurred in the same location as the August 21, 1952 event. The first, a small magnitude event with no associated magnitude or intensity, occurred on September 2, 1952. The second, an intensity III event, occurred on January 5, 1957. The most recent, an intensity IV event occurred on March 31, 1964. No damage was reported for any of the events.

On January 15, 1978, a magnitude 3.0, intensity III earthquake occurred approximately three miles northeast of Esterbrook, in Converse County. No damage was reported.
Two earthquakes occurred in Converse County in the 1980’s. On November 15, 1983, a magnitude 3.0, intensity III earthquake occurred approximately 15-miles northeast of Casper in western Converse County. No damage was reported. On December 5, 1984, a non-damaging magnitude 2.9 earthquake occurred in the Laramie Range in southern Converse County.

Four earthquakes occurred in Converse County in the 1990's. On June 30, 1993, a magnitude 3.0 earthquake was located approximately 15-miles north of Douglas. No damage was reported. On July 23, 1993, a magnitude 3.7, intensity IV earthquake occurred in southern Converse County, approximately 13-miles north-northwest of Toltec in northern Albany County. This event was felt as far away as Laramie. On December 13, 1993, another earthquake occurred approximately eight-miles east of Toltec. This non-damaging event had a magnitude of 3.5. Most recently, on October 19, 1996, a magnitude 4.2 earthquake was recorded approximately 15-miles northeast of Casper in western Converse County. No damage was reported, although the event was felt by many Casper residents.

Johnson County

Eight magnitude 2.5 and greater earthquakes have been recorded in Johnson County. The first earthquake recorded in the county occurred on October 24, 1922. The location was originally determined to be near Buffalo, and classified the event as an intensity II earthquake. Based upon a description of the earthquake in the October 27, 1922 edition of the Sheridan Post, however, the location and assigned intensity may be in error. The Sheridan Post reported that at Cat Creek, eight-miles east of Sheridan, houses were shaken and dishes were rattled. In addition, the October 26, 1922 edition of the Sheridan Post reports that only a slight earthquake shock was felt in Sheridan. Based upon this information, it seems reasonable to locate the earthquake eight miles east of Sheridan, and to assign an intensity of IV-V to the event.

On September 6, 1943, an intensity IV earthquake was felt in the Sheridan area, although the epicenter was determined to be approximately three to four miles south-southwest of Buffalo. Beds and chairs were reported "to sway" in the Sheridan area.

Two earthquakes were recorded in Johnson County in the 1960s. A magnitude 4.7 earthquake occurred on June 3, 1965. This event was centered approximately 12-miles south of Kaycee. On April 12, 1966, an earthquake of no specified magnitude or intensity was detected approximately 25-miles southwest of Buffalo. No one reported feeling these events.

On September 2, 1976, a magnitude 4.8, intensity IV-V earthquake was felt in Kaycee. The event was located approximately 33-miles northeast of Kaycee. No damage was reported.

A magnitude 5.1, intensity V earthquake occurred on September 7, 1984, approximately 33-miles east-southeast of Buffalo. The earthquake was felt throughout northeastern Wyoming, including Buffalo, Casper, Kaycee, Linch, and Midwest, and in parts of southeastern Montana. No significant damage was reported.

Two earthquakes were detected in Johnson County in 1992. The first occurred on February 22, 1992. This magnitude 2.9 event was recorded approximately 18-miles east of Buffalo. As expected with such a small earthquake, no damage was reported. Most recently, a magnitude 3.6, intensity IV earthquake occurred on August 30, 1992. The earthquake was centered near Mayoworth, approximately 22-miles west-northwest of Kaycee. It was felt in Barnum and Kaycee, but no damage was reported.

D5.4.2.2 Probablistic Seismic Hazard Analysis

The USGS publishes probabilistic acceleration maps for 500-, 1,000- and 2,500-year time frames. The maps show what accelerations may be met or exceeded in those time frames by expressing the probability that the accelerations will be met or exceeded in a shorter time frame. For example, a 10 percent probability that acceleration may be met or exceeded in 50 years is roughly equivalent to a 100 percent probability of exceedance in 500 years.

The USGS has recently generated new probabilistic acceleration maps for Wyoming (Case, 2000). Copies of the 500-year (10 percent probability of exceedance in 50 years), 1,000-year (five percent probability of exceedance in 50 years), and 2,500-year (two percent probability of exceedance in 50 years) maps can be found in Addendum D5-B. Until recently, the 500-year map was often used for planning purposes for average structures, and was the basis of the most current Uniform Building Code (UBC). Recently, the UBC has been replaced by the International Building Code (IBC), which is based upon probabilistic analyses. Campbell County adopted the IBC in 2005. The new IBC, however, uses a 2,500-year map as the basis for building design. The maps reflect current perceptions on seismicity in Wyoming. In many areas of Wyoming, ground accelerations shown on the USGS maps can be increased due to local soil conditions. For example, if fairly soft, saturated sediments are present at the surface, and seismic waves are passed through them, surface ground accelerations will usually be greater than would be experienced if only bedrock was present. In this case, the ground accelerations shown on the USGS maps would underestimate the local hazard, as they are based upon accelerations that would be expected if firm soil or rock were present at the surface. Intensity values and descriptions can be found in Table D5B-1 and D5B-2 in Addendum D5-B.

Based upon the 500-year map (10 percent probability of exceedance in 50 years) (Figure D5B-1), the estimated peak horizontal acceleration in Campbell County ranges from approximately three percent/g in the northeastern corner of the county to greater than 6 percent/g in the southwestern corner of the county. These accelerations are roughly comparable to intensity IV earthquakes (1.4 percent/g – 3.9 percent/g) to intensity V earthquakes (3.9 percent/g – 9.2 percent/g). These accelerations are comparable to the accelerations to be expected in Seismic Zones 0 and 1 of the Uniform Building Code.

Intensity IV earthquakes cause little damage. Intensity V earthquakes can result in cracked plaster and broken dishes. Gillette would be subjected to an acceleration of approximately five percent/g or intensity V.

Based upon the 1,000-year map (five percent probability of exceedance in 50 years) (Figure D5B-2), the estimated peak horizontal acceleration in Campbell County ranges from four percent/g in the northeastern corner of the county to greater than 10 percent/g in the southwestern quarter of the county. These accelerations are roughly comparable to intensity V earthquakes (3.9 percent/g – 9.2 percent/g) to intensity VI earthquakes (9.2 percent/g – 18 percent/g). Intensity V earthquakes can result in cracked plaster and broken dishes. Intensity VI earthquakes can result in fallen plaster and damaged chimneys. Depending upon local ground conditions, Gillette would be subjected to an acceleration of approximately nine percent/g or greater and intensity V or VI.

Based upon the 2,500-year map (two percent probability of exceedance in 50 years) (Figure D5B-3), the estimated peak horizontal acceleration in Campbell County ranges from eight percent/g in the northeastern corner of the county to greater than 20 percent/g in the southwestern corner of the county. These accelerations are roughly comparable to intensity V earthquakes (3.9 percent/g – 9.2 percent/g), intensity VI earthquakes (9.2 percent/g – 18 percent/g), and intensity VII earthquakes (18 percent/g – 34 percent/g). Intensity V earthquakes can result in cracked plaster and broken dishes. Intensity VI earthquakes can result in fallen plaster and damaged chimneys. Intensity VII earthquakes can result in slight to moderate damage in well-built ordinary structures, and considerable damage in poorly built or badly designed structures, such as unreinforced masonry. Chimneys may be broken. Gillette would be subjected to an acceleration of approximately 18 percent/g or intensity VI to VII.

As the historic record is limited, it is nearly impossible to determine when a 2,500-year event last occurred in the county. Because of the uncertainty involved, and based upon the fact that the new International Building Code utilizes 2,500-year events for building design, it is suggested that the 2,500-year probabilistic maps be used for Campbell County analyses. This conservative approach is in the interest of public safety.

Current earthquake probability maps that are used in the newest building codes (2,500-year maps) suggest a scenario that would result in moderate damage to buildings and their contents, with damage increasing from the northeast to the southwest. More specifically, the probability-based worst-case scenario could result in damage at points throughout Campbell County and surrounding areas as mentioned in Tables D5B-1 and D5B-2.

D5.4.2.3 Deterministic Analysis of Regional Active Faults with a Surficial Expression

There are no known exposed active faults with a surficial expression in Campbell County. As a result, no fault-specific analysis can be generated for Campbell County. Figure D5B-4 shows historic earthquakes and faults in relation to the Proposed Project.

D5.4.2.4 Floating or Random Earthquake Sources

Many federal regulations require an analysis of the earthquake potential in areas where active faults are not exposed, and where earthquakes are tied to buried faults with no surface expression. Regions with a uniform potential for the occurrence of such earthquakes are called tectonic provinces. Within a tectonic province, earthquakes associated with buried faults are assumed to occur randomly, and as a result can theoretically occur anywhere within that area of uniform earthquake potential. In reality, that random distribution may not be the case, as all earthquakes are associated with specific faults. If all buried faults have not been identified, however, the distribution has to be considered random. “Floating earthquakes” are earthquakes that are considered to occur randomly in a tectonic province.

It is difficult to accurately define tectonic provinces when there is a limited historic earthquake record. When there are no nearby seismic stations that can detect small-magnitude earthquakes, which occur more frequently than larger events, the problem is compounded. Under these conditions, it is common to delineate larger, rather than smaller, tectonic provinces.

The U.S. Geological Survey identified tectonic provinces in a report titled “Probabilistic Estimates of Maximum Acceleration and Velocity in Rock in the Contiguous United States” (Algermissen and others, 1982). In that report, Campbell County was classified as being in a tectonic province with a “floating earthquake” maximum magnitude of 6.1. Geomatrix (1988b) suggested using a more extensive regional tectonic province, called the “Wyoming Foreland Structural Province”, which is approximately defined by the Idaho-Wyoming Thrust Belt on the west, 104° West longitude on the east, 40° North latitude on the south, and 45° North latitude on the north. Geomatrix (1988b) estimated that the largest “floating” earthquake in the “Wyoming Foreland Structural Province” would have a magnitude in the 6.0 – 6.5 range, with an average value of magnitude 6.25.

Federal or state regulations usually specify if a “floating earthquake” or tectonic province analysis is required for a facility. Usually, those regulations also specify at what distance a floating earthquake is to be placed from a facility. For example, for uranium mill tailings sites, the Nuclear Regulatory Commission requires that a floating earthquake be placed 15 kilometers from the site. That earthquake is then used to determine what horizontal accelerations may occur at the site. A magnitude 6.25 “floating” earthquake, placed 15 kilometers from any structure in Campbell County, would generate horizontal accelerations of approximately 15 percent/g at the site. Critical facilities, such as dams, usually require a more detailed probabilistic analysis of random earthquakes. Based upon probabilistic analyses of random earthquakes in an area distant from exposed active faults (Geomatrix, 1988b), however, placing a magnitude 6.25 earthquake at 15 kilometers from a site will provide a fairly reasonable estimate of design ground accelerations in the northeastern and eastern parts of Campbell County, but will be inadequate in the southerstern part of the county.

D5.5 References

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