Energy and Mineral Resources Mining Contradictions in Coal-Uranium Coexisting Basin and the Countermeasure Suggestions

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\textbf{Abstract:} It is common that sandstone-type uranium deposits co-exist with coal and oil & gas in the same sedimentary basin, and the output of uranium deposits is closely related to the coal seam or oil & gas reservoir. An “upper uranium and lower coal” ore-bearing pattern is formed in Ordos Basin and Erlian Basin in China. Due to the absence of unified resource mining plan and policy coordination mechanism, the coal-uranium resource mining contradictions have become increasingly prominent in coal-uranium coexisting areas in recent years. It is difficult to realize in-situ leaching exploitation of the coal-uranium resources in the Ordos coal-uranium coexisting area because of disorderly mineral resource mining, radioactive contamination risks are posed to the ambient environment of the mining area, and consequently, coal mine enterprises have to stop work and production, which gives rise to huge economic loss. Given this, the current resource contradictions in this area and their influence paths were comprehensively expounded through a systematic survey on a coal-uranium superposition area, and then the corresponding countermeasure suggestions were proposed.

\section{1. Introduction}
As an independent reservoir forming system, sedimentary basin abounds in energy mineral resources such as oil, gas, coal and uranium, etc., which are of great significance to national economy and energy safety (Wang F F, 2018; Liu C Y et al., 2017)\textsuperscript{[1]}. Although the utilization rate of coal resource, which is a traditional energy mineral resource, is continuously reduced thanks to environmental policies like energy conservation and emission reduction, it is hardly replaceable by other energy resources in some fields; as the main source of nuclear energy, uranium is not only a clean energy but also a strategic resource of military-civilian dual use. With the development of the nuclear power industry in China, the quantity of natural uranium demanded is continuously increasing, and the domestic supply could hardly satisfy the domestic demand. The uranium-coal/oil & gas coexistence in the same basin becomes a universal phenomenon on account of the positive role played by coal and oil & gas-related reductants in the hydrogenic uranium deposit forming process as well as the unique metallogenic model of sandstone-type uranium deposits, and moreover, the output of the sandstone-type uranium deposits is usually closely associated with coal seams or oil & gas reservoirs.
Figure 1. Source-sink formation process of energy mineral resources in sedimentary basin (Liu C Y et al., 2016)

The exploration of sandstone-type uranium ores has a late start in China, lagging behind the exploration conducted by coal field sectors, so the development degree and progress of the sandstone-type uranium resources fall behind coal resources. In shortage of a unified mining plan, it is difficult to overcome the industry barriers between different sectors, a series of mining contradictions and environmental risks are generated in the later-stage resource development process, and the coal-uranium resource development contradictions are especially prominent in the Ordos area.

Table 1. Oil & gas and coal-uranium coexisting relations in Ordos Basin

| Stratum       | Sedimentary facies | Sedimentary minerals | Main occurring mineral |
|---------------|--------------------|----------------------|------------------------|
| Erathem       |                    |                      |                        |
| Cenozoic      |                    |                      |                        |
| Quaternary    | alluvial-proluvial facies | Oil | Gas | Coal | U |
| Neogene       | Fluvial and limnetic facies |              |                        |
| Jurassic      | Fluvial facies     | Uranium              | Coal                   |
| Cretaceous    |                    |                      |                        |
| Jurassic      | Flood plain facies |                      |                        |
| Triassic      | Fluvial facies     | Oil                  |                        |
| Mesozoic      | Delta facies       |                      |                        |
| Triassic      | Fluvial-limnetic transitional facies | Oil | | | |
2. Typical Coal-uranium Coexistence in the Same Basin

2.1 Coal-uranium superposition status in the Ordos area

The Ordos area is located at the northeast part of Ordos Basin, where the coal reserves already explored reach over 149.6 tons, accounting for about 1/6 of national total coal reserves; since the 21st century, a batch of super-large and ultra-large sandstone-type uranium ore deposits have been successfully discovered by the nuclear industrial system in this area, and thus it becomes an important natural uranium reserve base.

Both coal seam and uranium ore deposit derive from Mesozoic stratum in the study area. The coal-bearing series mainly include Triassic Yanchang Formation and Jurassic Yan’an Formation, while uranium ore body mainly emerges from Jurassic Zhiluo Formation (Table 2). From the spatial angle, the uranium ore deposits in the Ordos area are covered on the main coal seam Yan’an Formation as a whole, presenting the “upper uranium and lower coal” pattern, the vertical distance from the uranium ore deposit to the top interface of Yan’an Formation is within 60 m-100 m, where the minimum vertical distance is only 20 m.

When it comes to plane relations, the sandstone-type uranium ore deposits already discovered in the Ordos area present spatial superposition relations with the demarcated scope of coal mining rights or explored coal mines to different degrees (Figure 2). For instance, Daying Uranium Ore Deposit is completely located on the coal mining area explored by the Central Geological Exploration Fund; Nalinggou Uranium Ore Deposit lies within the scope of coal mining right demarcated in Taran Gaole Coal Mine of Dongsheng Coal Field belonging to Shenhua Group.

![Figure 2. Coal-uranium resources superposition status in the Ordos area](image)

Except that the coal field general survey area of Central Geological Exploration Fund superposed with Daying Uranium Ore Deposit is not developed yet, and that Shenhua Taran Gaole Coal Mine is temporarily out of service because of the superposition with Nalinggou Uranium Ore Deposit, the coal mines in other coal-uranium superposition areas are under production state (Table 2).
Table 2. Development overview of Ordos coal-uranium superposition area

| Name of uranium ore deposit | Scale   | Name and serial number of superposed coal mining area | Superposition area (km²) | Coal mine status |
|-----------------------------|---------|------------------------------------------------------|--------------------------|------------------|
| Daying                      | Super-large | Coal field of Central Geological Exploration Fund (1) | Whole uranium deposit   | Undeveloped     |
| Nalinggou                  | Ultra-large | Taran Gaole Coal Mine (2) | 8.5 | Production halt |
| Caidenghao                 | Middle-size | Gaotouyao Coal Mine (3), Selian 2# Coal Mine (4) | 10.7 | In production |
| Zaohuohao                  | Ultra-large | Wangjiata Coal Mine of New Energy Mining Industry (5), Gaojialiang Coal Mine of Haohua Clean Coal (7) | 20 | In production |

2.2 Impact analysis of coal-uranium resources mining

As the whole uranium reservoir-middle Jurassic Zhiluo Formation is covered on the coal seam of Yan’an Formation, the aquifer in the former formation becomes the main water filling source of the latter. In the coal-uranium resource co-existing area, the sewer drainage for the aquifer in the upper Zhiluo Formation during the mining process of the coal seam in Yan’an Formation will lead to sudden drop of groundwater level in the aquifer of the uranium ore deposit. The in-situ leaching mining of the sandstone-type uranium ore can be implemented only when the aquifer keeps a certain hydraulic head, so it will be hard to realize in-situ leaching mining in the future due to the decline of the groundwater level in the aquifer.

In addition, the “three zones” formed in the goaf due to roof caving upon the completion of underground coal mining directly establishes a hydraulic connection between uranium ore aquifer and underlying formation, thus further causing the groundwater recession in the aquifer; the deformation of the uranium ore is caused by the instability of overlying strata in the roof caving process (Figure 3). Furthermore, in Zaohuohao Uranium Ore Deposit with low confined water head, the groundwater recession in the aquifer changes its redox conditions, and leads to uranium activation and migration.

![Figure 3. Impact of “three zones” in coal mine goaf on aquifer of uranium ore deposit](image)

1-Caving zone; 2-Fissure zone; 3-Bending subsidence zone; 4-Uranium ore; 5-Coal seam; 6-Lower confining bed (uranium ore); 7-Upper confining bed (uranium ore); 8-Groundwater flow direction; ① Stable moving boundary of rock strata; ② Initial moving boundary of rock strata

Due to the impact of sewer drainage engineering and “three zones” in the goaf on the aquifer of the uranium ore, the migration risk of in-situ leaching solution with high uranium concentration to
working seam exists during the in-situ leaching mining process of the sandstone-type uranium ore. As the mining conditions in Nalinggou Uranium Ore Deposit have become mature in recent years, extensive attention has been paid to the resource development contradictions in this coal-uranium co-existing area. The coal mining on the Zaohuohao Uranium Ore Deposit in the east of Ordos has exerted even more serious impact on the aquifer of the uranium ore, which, however, has not been given enough attention to.

3. Resource Development Contradictions in Typical Areas

3.1 Nalinggou area

Nalinggou Uranium Ore Deposit is located within Dalad Banner in Ordos City, the superposition area of its northern ore body with Shenhua Taran Gaole Coal Mine is about 8.5km², and the working face in the early-stage mining test is about 5 km away from Nalinggou Uranium Ore Deposit. During this coal mining test, a large-scale drainage & dewatering project was implemented for the upper water filling source, a cone of depression of regional groundwater level was then formed, which further resulted in sharp groundwater recession in the aquifer of the uranium core in Nalinggou area (Figure 4).

Before the coal mining test, the groundwater in the Zhiluo Formation aquifer on the Nalinggou Uranium Ore Deposit flowed from the northeast towards the southwest as a whole, the groundwater flow direction was consistent with the attitude of strata and regional groundwater runoff direction, and the hydraulic slope of the aquifer was gentle, only being 0.6‰.

Impacted by the large-scale sewer drainage engineering after the completion of the coal mining test, the Zhiluo Formation aquifer in Nalinggou area already formed an obvious cone of groundwater depression, the center of which was nearby the working face of pilot production. The waterhead from the uranium ore deposit to the center of the cone of depression reached 76.46 m, the average hydraulic slope of the aquifer reached 12.4‰, and the groundwater level dropped by 17.27 m within the scope of the uranium ore deposit.

![Figure 4. Comparison chart of groundwater flow fields in uranium ore aquifer in Nalinggou area](image)
In consideration of the impact of the sewer drainage engineering of Taran Gaole Coal Mine on the uranium ore aquifer, the production was halted since the coal mining test in 2013, in an effort to guarantee the later-stage uranium ore development. Due to the coal-uranium superposition in this area and the lack of overall planning, the risks exist in the later-stage uranium ore development, which impose enormous economic losses on coal mine enterprises.

3.2 Zaohuohao area
Zaohuohao Uranium Ore Deposit is about 20 km to the south of Dongsheng District, Ordos City. From east to west, the ore deposit is divided into four sections: Sunjialiang, Shashagetai, and Zaohuohao-Xinmiaohao, where the coal-uranium superposition area is located at Sunjialiang section in the east of the ore deposit. The uranium ore deposit is superposed with Wangjiata Coal Mine of New Energy Mining Industry Co., Ltd, and Gaojialiag Coal Mine of Haohua Clean Coal Co., Ltd, with total superposition area of about 20 km² (Figure 2). Wangjiata Coal Mine lies at the southwest of the uranium ore deposit. The construction roadway entered the scope of this uranium ore deposit in 2018, and the sewer drainage engineering in the coal mine not only caused sharp groundwater recession of the aquifer but also gave rise to uranium activation and migration.

By comparing the observational data of water levels before coal mining (2010) and that in 2018, it could be seen that a cone of groundwater depression was already formed in the uranium ore aquifer, and the decreasing amplitude of groundwater level at the center of the cone reached 58.67 m (Figure 5).
The height of the confined water head in the uranium ore aquifer ranged from 17.14 to 82.23 m before the coal mining; until 2018, the height declined to 2.66-54.22 m, and the confined water head at the center of the cone was only kept at 2.66 m. With declining confined water head of the aquifer and accelerated groundwater runoff, the forward line of the upstream oxidizing zone in the uranium ore aquifer presented westward displacement, the aquifer was transformed from weak oxidation-transitional environment into weak oxidation environment, which aggravated the uranium dissolution in water and migration. Before the coal mining, the uranium concentration was 0.01~92 μg/L in water of the uranium ore aquifer, but it rose to 8.51-637 μg/L after the coal mining (Table 3), and the uranium concentration in water nearby the forward line of the oxidizing zone was increased by 1,027 times.

Table 3. Comparison of redox indexes in uranium ore aquifer and uranium concentrations in water in different periods

| Observation well No. | Height of confined water head (m) | Eh value (mV) | Uranium concentration in water (μg/L) |
|----------------------|-----------------------------------|--------------|-------------------------------------|
|                      | 2010 | 2018 | 2010 | 2018 | 2010 | 2018 | 2010 | 2018 |
| W5                   | 82.23 | 54.22 | -148 | -75.5 | 0.2 | 20.6 |
| W3                   | 69.78 | 32.05 | / | 24.6 | / | 8.51 |
| W8                   | 61.33 | 2.66 | -195 | 67.2 | 2.6 | 23.5 |
| W6                   | 47.9 | 16.26 | / | 70.6 | 2.6 | 8.92 |
| W19                  | 36.48 | 4.95 | / | 110 | 64 | 19.4 |
| W9                   | 17.14 | 5.32 | 127 | 57.3 | 0.031 | 23.7 |
| W13                  | 17.26 | 17.74 | - | 332 | 0.62 | 637 |

To sum up, enormous damage has been caused to the overlying uranium ore aquifer during the coal resources mining process in the Zaohuohao coal-uranium superposition area due to the lack of systematic planning and effective supervision. In-situ leaching mining cannot be realized any longer with the present confined water head and geological conditions in the uranium ore deposit at the Sunjialiang section. What’s worse, with the continuous displacement of aquifer oxidizing zone, the groundwater with high uranium concentration will be discharged out of the surface because of the sewer drainage engineering, thus causing the radioactive pollution risks to the surrounding water environment and soil environment.

4. Conclusions and Suggestions

4.1 Conclusions

The sandstone-type uranium ore deposit already discovered in the Ordos area is superposed with all underlying coal seams to different degrees. Lacking unified planning and orderly resource development mechanism, the coal-uranium resource development contradictions become increasingly prominent during the local large-scale coal resource mining process. In Nalinggou area and Zaohuohao area, the coal mining has destructed both uranium ore aquifer and uranium ore body, which causes an adverse effect on the later-stage uranium ore mining; the production is halted after the construction of the coal mine is completed in order to protect the uranium ore, which also brings about considerable economic losses to the coal mine enterprises. In other coal-uranium superposition areas,
however, no systematic survey and monitoring are carried out. Furthermore, the coal-uranium resource contradictions and their impact degrees in Daying area and Caidenghao area remain to be figured out.

4.2 Suggestions
In view of the current coal-uranium resource contradictions in the Ordos area, it is suggested that the uranium ore development should be accelerated on the precondition of “space-time staggering, uranium first and coal second”, so as to create conditions for putting coal mines into production as soon as possible, and reduce the loss imposed on the owner of coal mining right. The coal, uranium, oil & gas and other resources should be comprehensively considered in the resource prospection process. The comprehensive exploration and prospection results should be improved by taking full advantages of financial investments. In the areas with coal-uranium coexistence conditions, the regulatory and leading functions of the government should be strengthened, and an orderly development and unified planning mechanism should be established as soon as possible to promote the sustainable development of mineral resources, and eliminate the hidden environmental risks.

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