

Patterns and Features of Global Uranium Resources and Production

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Abstract: With the entry into force of the Paris Agreement, the development of clean and low-carbon energy has become the consensus of the world. Nuclear power is one energy that can be vigorously developed today and in the future. Its sustainable development depends on a sufficient supply of uranium resources. It is of great practical significance to understand the distribution pattern of uranium resources and production. Based on the latest international authoritative reports and data, this paper analysed the distribution of uranium resources, the distribution of resources and production in the world, and the developing tendency in future years. The results show that the distribution of uranium resources is uneven in the world, and the discrepancies between different type deposits is very large. Among them, sandstone-type uranium deposits will become the main type owing to their advantages of wide distribution, minor environmental damage, mature mining technology and high economic benefit.

1. World primary energy structure and developing trend

The latest BP Energy Outlook (2017 edition) shows that coal, oil and natural gas remain an absolute leading position in the composition of primary energy consumption of the world, 85% of that are these three (Fig. 1). But nuclear power, hydro power and renewable energy are quietly changing as relatively low-carbon clean energy. Some prediction offered in the report as follows: Oil and coal in the next 20 years will reduce by 20%; Natural gas and renewable energy will significantly increase their proportions; Nuclear power will rise to about 6% (BP, 2017). With signing of the Paris Agreement, this trend will become increasingly widespread impacting and changing our way of life, especially in transportation and production of industrial and agricultural.

Most European countries have a high proportion of nuclear power in total electric power. Of which France reached 73.3%, 40%~50% in Ukraine and Sweden. The number is also relatively big in the United States, Russia and South Korea. Affected by the Fukushima-Daichi nuclear power plant accident in recent years, Japan gradually reduced the proportion of nuclear from the original 30% to 1.7% today. Only 2% of China's electricity comes from nuclear power.



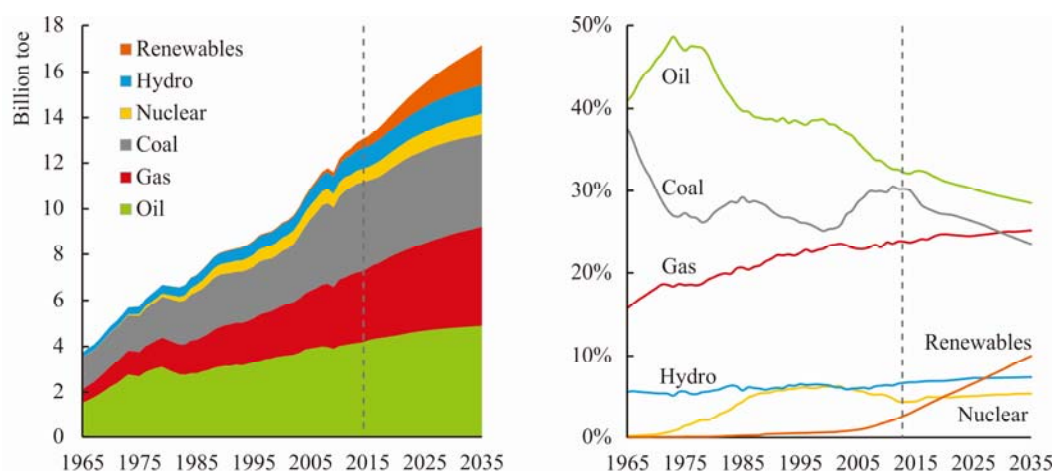


Figure 1. Primary energy consumption by fuel (left) and shares of primary energy (right)

Uranium resources are the basic material guarantee of developing nuclear. The amount of the former directly affects the sustainable development of the latter. In addition, the uranium resources, as military strategic resources, have special significance. Therefore, the resources (reserves) and production of uranium have been paid much attention. It has crucial practical significance to study their distribution characteristics.

2 Classification of uranium deposits

Uranium deposits are classified into 15 major types according to the differences of genesis, main host rocks and producing geological environment in latest scheme recommended by International Atomic Energy institutions (IAEA). It is arranged according to their approximate economic significance as the following: sandstone deposits, Proterozoic unconformity deposits, polymetallic Fe-oxide breccia complex deposits, paleo-quartz-pebble conglomerate deposits, granite-related, metamorphite, intrusive deposits, volcanic-related deposits, metasomatic deposits, surficial deposits, carbonate deposits, collapse breccia-type deposits, phosphate deposits, lignite and coal, black shale (IAEA, 2009; OECD/NEA-IAEA, 2016).

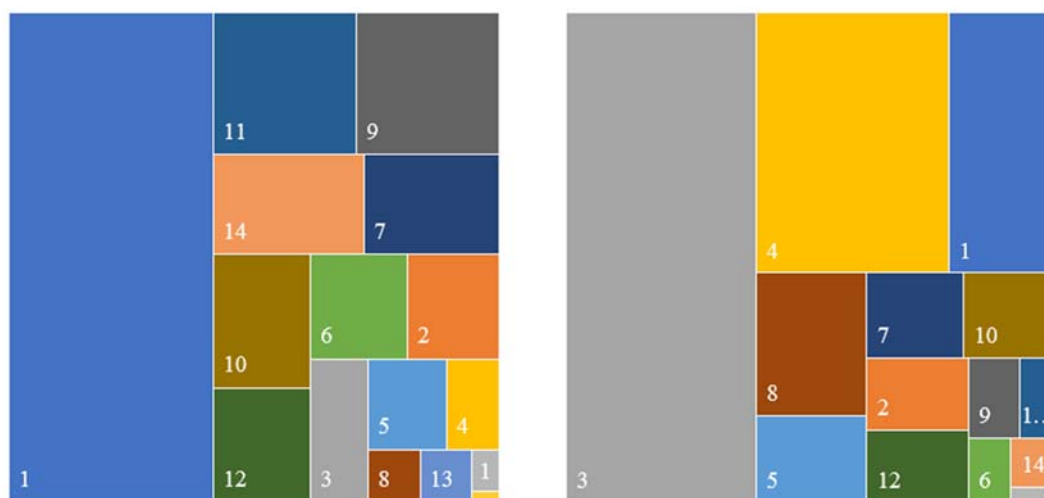
This scheme for classification avoids some shortcomings that may be caused only by the deposit genesis. Their main host rocks of the deposits will not easily change once they are identified correctly. So, it is practicable and less controversial in exploration and research (Yu Dagan et al., 2004; Dahlkamp, FJ, 2009; OECD/NEA-IAEA, 2016).

3 Uranium resources and their characteristics in the world and the main uranium producing countries

3.1 The number and amount of uranium deposits in the world

The latest UDEPO database of IAEA shows that the world has found 15 types of uranium deposits, 1520 in total, distributing among 75 countries. Sedimentary types, 887 in total, account for 58% of all types. 639 sandstone uranium deposits are included, accounting for 71% of sedimentary uranium deposits and 42% of the total uranium deposits in the world (Figure 2, left).

It can be found from the UDEPO database that the total original resources (including cumulative production and remaining resources) of the world are 3504×10^4 t U. Of which the sedimentary uranium resources account for 79%, including the most abundant three types: phosphate, lignite-coal and sandstone. Each of the three accounts for 49%, 26% and 15% of the sedimentary resources in this order (Fig. 2, right). The former two belong to unconventional uranium resources, which are difficult and expensive to be mined at present, only little production in individual countries. Therefore, sandstone-type uranium deposits have the largest proportion of conventional uranium resources, regardless of the quantity or the amount of the original resources.



Note: 1 sandstone; 2 Paleo-quartz-pebble conglomerate; 3 Phosphate; 4 Lignite and coal; 5 Black Shales; 6 Surficial; 7 Proterozoic unconformity; 8 Polymetallic iron-oxide breccia complex; 9 Volcanic; 10 Intrusive; 11 Granite-related; 12 Metasomatite; 13 Collapse Breccia Pipe; 14 Metamorphite; 15 Carbonate

Figure 2. Quantitative proportion (left) and resource proportion (right) of all types of uranium deposits in the world

It is usually more practical to represent the amount of uranium resources by the identified resources (RAR+IR) or the reasonably assured resources (RAR) under the economic recoverable ($< \$ 130/\text{kg U}$) condition. Data from Uranium Red Book (2011), published by the OECD Nuclear Energy Agency (NEA) and IAEA, shows that of global identified resources (RAR+IR) (the cost $< \$ 130/\text{kg U}$), the sandstone deposits account for 32%. Followed by the Fe-oxide breccia complex deposits and Proterozoic unconformity deposits. The paleo-quartz-pebble conglomerate deposits account for 5% and other sedimentary types (phosphate deposits, lignite-coal and black shale) account for 7%. That is, the total sedimentary uranium resources account for 44% of all.

3.2 Resources of the main uranium producing countries

Identified resources (RAR+IR) of the world's top five countries are Australia (1706100 t U), Kazakhstan (679300 t U), Russia (505900 t U), Canada (493900 t U), and Niger (404900 t U). The world distribution of uranium resources is extremely uneven, with the top 15 countries accounting for 95% of the total (Fig. 3). The ranking according to reasonably assured resources (RAR) is slightly different from the above (Fig. 4).

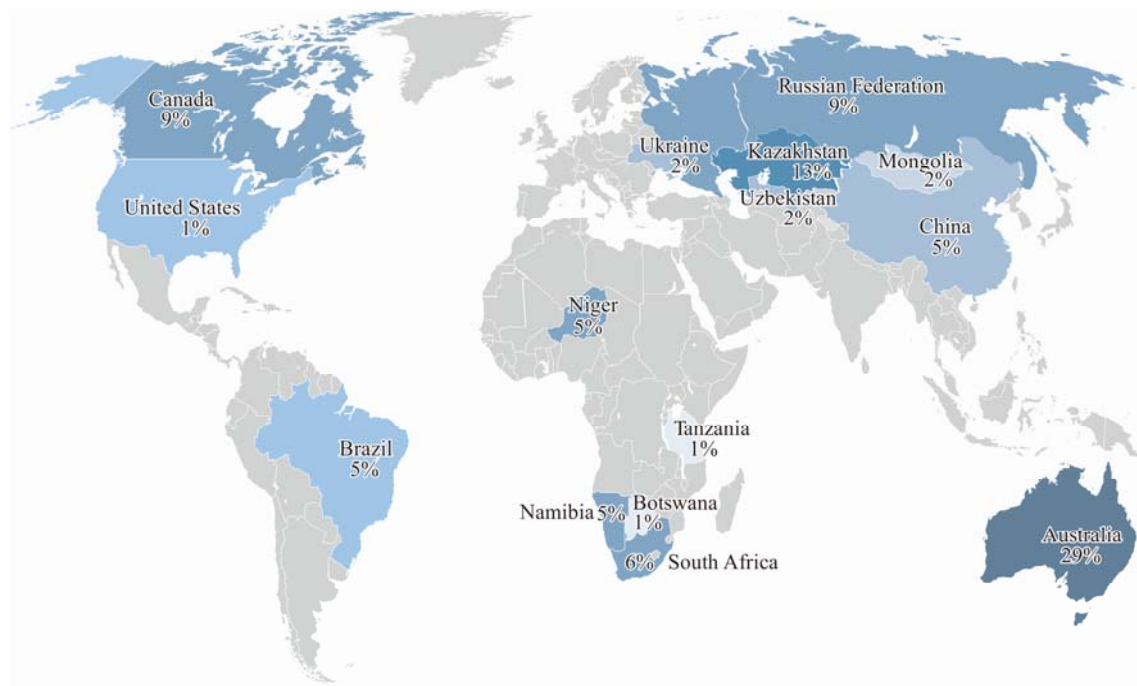


Figure 3. Global distribution of identified resources (RAR+IR) and its shares in the world

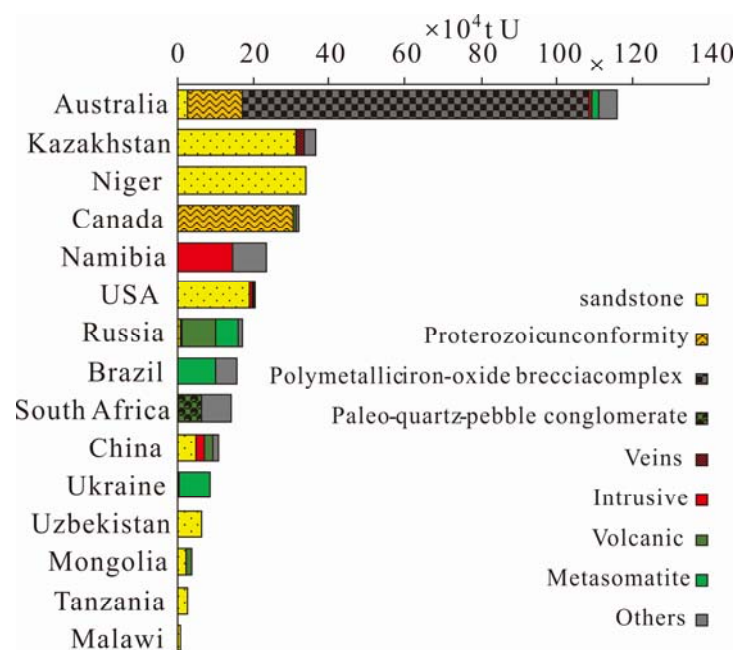


Figure 4. Uranium resources (RAR, <\$ 130/kg U) of the world's major uranium-producing countries (Data are collected from OECD/NEA-IAEA, 2012)

The resource composition of the major uranium-producing countries (Fig. 4) shows some information. Almost all the Polymetallic Fe-oxide breccia complex deposits are from Australia, and the Proterozoic unconformity deposits are almost entirely from Canada and Australia. More than 99% of the world's identified resources are from these two countries. While the rest of the world has little chance to find such large deposits in the future. Therefore, it can't reflect the global universality in the aspects of uranium mineralization regularity and distribution characteristics if the above types are included in total resources. It is reasonable to treat these two types of deposits as special cases. After removing these

two types, the sedimentary uranium account for 65% of the globe.

4 Uranium production and its characteristics

The world produced uranium 59531 t U in 2013. The top three countries are Kazakhstan (39%), Canada (22%), Australia (9%). That is, more than 2/3 of total production comes from these three countries. Followed by Niger and Namibia.

According to the latest information from IAEA, the world produced 28277 t U uranium with in situ leaching (ISL) by 2013, accounting for 47.5% of production with all methods. Followed by production with open-pit mining and underground mining, accounting for 18.5% and 25.6%. All rest production with by-product recycling, heap leaching, and other forms account for less than 9%. Niger, Malawi and other countries still produce sandstone uranium with traditional open-pit or underground mining due to geological conditions, technology or other reasons. If this part of production is taken into account, the sandstone uranium production all of the world will totals at least 33,336 t U, accounting for 56% of all types of world uranium production.

The world's largest 15 uranium deposits contributed 66.4% of the world's total production. Nine of them were sandstone-type (Table 1), and account for about 1/3 of total all type uranium production of the world.

Table 1. The largest-producing uranium mines in 2016 (Data are collected from WNA)

No.	Mine	Country	Types of uranium deposits	Production method	Production (t U)	% of world
1	McArthur River	Canada	Proterozoic unconformity	underground	7354	12
2	Cigar Lake	Canada	Proterozoic unconformity	underground	4345	7
3	Tortkuduk & Myunkum	Kazakhstan	sandstone	ISL	4109	7
4	Olympic Dam	Australia	polymetallic iron-oxide breccia complex	by-product	3179	5
5	SOMAIR	Niger	sandstone	open pit	2509	4
6	Inkai	Kazakhstan	sandstone	ISL	2234	4
7	Budenovskoye 2	Kazakhstan	sandstone	ISL	2061	4
8	South Inkai	Kazakhstan	sandstone	ISL	2055	3
9	Priargunsky	Russia	sandstone	underground	1977	3
10	Langer Heinrich	Namibia	surficial deposits	open pit	1937	3
11	Central Mynkuduk	Kazakhstan	sandstone	ISL	1847	3
12	Ranger	Australia	Proterozoic unconformity	open pit	1700	3
13	Budenovskoye 1, 3 & 4	Kazakhstan	sandstone	ISL	1642	3
14	Rabbit Lake	Canada	Proterozoic unconformity	underground	1621	3
15	COMINAK	Niger	sandstone	underground	1607	3
Sandstone total			9		20041	33.12%
Top 15 total			15		40177	66.40%

The shares of sandstone-type uranium production accounted for an important position in the world top ten uranium producers except Canada, Australia and Namibia in 2012. 98% production in Kazakhstan comes from sandstone type. The 4th (Niger), 7th (Uzbekistan) and 10th (Malawi) countries produce uranium all from sandstone. Production from sandstone account for 21% and 27% in Russia and China, and perhaps more than 80% in U.S. under estimation based on its number of uranium producing center. Overall, 57% of the uranium production in these top ten countries come from sandstone-type uranium deposits. The data is almost equals the above share (56%) of the globe.

The statistical results show that total uranium production increased by 64% from 2003 to 2013. 86% of the new increment came from ISL. With a rapid increase of sandstone uranium production, the share of total production reach more than 47.5% since 2013. This is mainly contributed by Kazakhstan, Niger, Uzbekistan, Malawi, Russia and China. The production by ISL has been the first in various production methods since 2009. In other words, sandstone-type uranium deposits contribute the vast majority of annual increment production in the world now and in future years.

5 Conclusion

(1) The distribution of world uranium resources is widely and uneven. Kazakhstan, Canada, Australia, Nigeria and Namibia have the largest amount of resources and production. The top 15 countries account for 95% of the global resources, and the top three countries account for 2/3.

(2) Three types (Proterozoic unconformity deposits, polymetallic Fe-oxide breccia complex deposits, and sandstone deposit) of uranium deposits account for the vast majority of the total resources and production. But the former two only distribute in very few countries such as Canada and Australia. Sandstone deposits have a widely distribution.

(3) In the view of time going, resources, production and annual new increment production of sandstone uranium deposits rank first in all type uranium deposits in recent years. More than half of world uranium production comes from sandstone uranium deposits, and the share is still increasing. Sandstone uranium deposits will become the main type owing to their advantages of wide distribution, minor environmental damage, mature mining technology and high economic benefit. Its significance and this tendency will be more obvious, as long as the share of nuclear energy in the primary energy keep on increasing.

Acknowledgments

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