Uranium Exploration, Deposit and Resources: The Key of Nuclear Power Plant Development Program in Indonesia

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Abstract. Uranium deposit in Indonesia was found in almost all Indonesian Archipelago, mainly in Kalimantan, Sulawesi, Sumatera, Papua, Bangka Belitung and Riau islands. Uranium exploration activities started in the 1960s to recent, conducted in many exploration stages. The exploration in prospects area are completed with drilling activities to delineate the mineralization zone and continued to resources estimation. In Kalan Area, the research had been completed with underground/tunneling mining. The uranium resources are classified into discovered or undiscovered based on exploration stages, and conventional or unconventional based on sources of primary/secondary/by-product mineral production. The resources are calculated from Kalan Area and its surroundings (Kalimantan) with addition of Mamuju Area (West Sulawesi) and Sibolga Area (North Sumatera). Uranium identified resource in Indonesia is 13,503 tU while the undiscovered is 62,330 tU. Meanwhile, categorized by uranium source, the conventional and unconventional resources are 48,388 tU and 27,445 tU respectively. The uranium resources categories should be increased and completed with feasibility study to increase the resources to reserve classification. The exploration, deposit, and resources are the key to ensure the readiness of developing nuclear power plants in Indonesia, where one of them is Experimental Power Reactor (EPR) or Reaktor Daya Eksperimental (RDE) with domestic uranium fuel.

Keywords: uranium, deposit, exploration, geology, resources, RDE

1. Uranium Exploration and Mine Development

National Nuclear Energy Agency (BATAN) has launched the program to develop Experimental Power Reactor (EPR) or generally known as Reaktor Daya Eksperimental (RDE) in year 2015. This program has increased the enthusiasm for various supporting sectors to contribute, one of which is the uranium resources as baseline for nuclear fuel support in future development.

The uranium resources itself, was first investigated by the Directorate Survey of Geology, now Center for Nuclear Minerals Technology (PTBGN), was formed in 1969 in order to explore the uranium deposits in Indonesia. The uranium exploration stages, applied the scheme of IAEA, from Preliminary Prospect, General Prospectation, Detail Prospectation, and Systematic Prospectation. Nowadays with the terminology of United Nations Frameworks Classification (UNFC), the stages is more general and also nationally in line with Indonesian National Standard (SNI) [1]–[3] (Table 1).

The uranium exploration in Indonesia is started in 1960s. Important stage in exploration activity is in 1969 when uranium exploration cooperation signed by Indonesia (National Nuclear Energy Agency-BATAN) and France (Commissariat a l’energie atomique-CEA). The exploration cooperation started with general exploration in Schwaner Mountain and surrounding region in West to East Kalimantan which covers area of 266,000 km². The exploration cooperation is successfully found some area contained uranium deposit, named Kalan and Mahakam Hulu. In 1974 exploration...
cooperation focused in Kalan and Melawi-Mahakam. In 1977 cooperation is terminated and the exploration activity is done solely by BATAN.

### Table 1. Exploration stages of BATAN and comparison to others standard

| EXPLORATION STAGES | BATAN | IAEA (1988) | SNI (2002) | UNFC (2009) |
|--------------------|-------|-------------|------------|-------------|
| Reconnaissance     | Planning and Area Selection | Reconnaissance Survey | Reconnaissance Survey |
| Preliminary Prospection (scale 1:250,000) | | | |
| General Prospection (scale 1:100,000) | Reconnaissance Phase (scale 1:250,000-1:100,000) | | |
| Detail Prospection (scale 1:5,000-1:10,000) | Follow-Up Phase (Scale 1:5,000-1:25,000) | General Exploration | General Exploration |
| Systematic Prospection (1:1000-1:2,000) | Detailed Phase (1:5,000-1:500) | Detail Exploration | Detail Exploration |

After the period of collaboration between BATAN and France’s CEA in 1977, the exploration program focused on Kalan Area, West Kalimantan which had the most significant uranium mineralization indication by that time. Research of exploration, mining and processing is on its peak in 1981 when Eko-Remaja tunnel started. The tunnel cut the ore body and the Eko Hill as the same time. In 1986 main tunnel is reached other slope-front of Eko Hill for the length of 618 m. The tunnel continues for research of mining and processing. Also started in 1981, processing pilot plant is started in Lemajung for processing ore from Eko-Remaja. Research processing is running for 10 years and it’s ended in 1996 with 740 kg of yellow cake produced.

After the ceased of the Eko-Remaja, exploration rate is decreased but still focused in Kalan and its surrounding area, includes Mentawa (Central Kalimantan) consisted of systematic geological and radiometric mapping, and radon survey. In early 2000’s, additional exploration drilling was started in Kalan at Jumbang, Mentawa, and Semut sectors [4]. In 2009, systematic prospection in the Kawat area, Mahakam, was carried out. General prospection in Bangka Belitung Province was also undertaken.

Uranium and thorium exploration re-focused to Mamuju, West Sulawesi after first major discovery in 2012 from program of regional environmental radiation dose-rate mapping. In 2013 preliminary survey is conducted in Mamuju region and successfully delineated several interesting sectors for further exploration target [5]. Detailed ground radiometric mapping was conducted in the Takandeang, Taan, Ahu, Pangasaan, and Hulu Mamuju sectors. Geophysical resistivity and induced polarisation surveys conducted in the Botteng and Takandeang sectors were followed by reconnaissance drilling in 2015 for a total depth of 1,600 m. Drilling targets were anomalous uranium occurring as stratabound and supergene enrichment in volcanic deposits. In the same year of 2015 exploration in the Ella Ilir area, West Kalimantan included geological and radiometric mapping, and reconnaissance drilling with 400 m of total depth is conducted. The drilling in this area focused on uranium veins in metapelitic schistose and metatuff.

Regional geophysical survey includes ground geomagnetic, gravity, resistivity measurements, and seismic had started in the Mamuju area. In 2019, reconnaissance drilling for total length of 425 m is conducted in Pasa’bu and Takandeang sector.

Year of 2019 is the last year of 2015 - 2019 strategic plans, and the 3rd year of new Indonesian government policy in research program of National Research Priority (PRN) 2017-2045. The PRN is expecting actual and deliverable research target. In the sense of exploration project, it is consistently adding the scoping study for every project. More economic deposit has to be prioritizing to allow near
future development. The basin uranium exploration is firstly implemented and some radon anomaly is found in Melawi Basin, West Kalimantan as model for further basin approach development.

2. Uranium Deposit and Resources

Uranium occurrences by definition are a naturally occurring or anomalous concentration of uranium. Uranium deposit is a mass of naturally occurring mineral from which uranium could be exploited at present or in the future, and resources is total amount of uranium in the deposit [6], [7]. In resources reporting, generally it is divided into Identified Resources and Undiscovered Resources (Table 2).

Identified resources composed by Reasonably Assured Resources (RAR) and Inferred Resources (IR), it is referring to uranium deposits delineated by sufficient direct measurement to conduct pre-feasibility studies, and in some cases feasibility studies. In term of RAR, high confidence in estimates of grade and tonnage are generally compatible with standards for making the decision to proceed with of the project. Inferred Resources (IR) are not defined with a high a degree of confidence and generally require further direct measurement prior to making a decision to develop the project [8].

Undiscovered resources (prognosticated and speculative) refer to resources that are expected to occur based on geological knowledge of previously discovered deposits and regional geological mapping. Prognosticated resources (PR) refer to those expected to occur in known uranium provinces, generally supported by some direct evidence. Speculative resources (RS) refer to those expected to occur in geological provinces that may host uranium deposits. Both prognosticated and speculative resources require significant amounts of exploration before their existence can be confirmed and grades and tonnages can be more accurately determined. All PR and SR are reported as in situ resources [8], [4]. Intended for the ease of understanding of the resource category, comparison to other resources reporting is described in Table 2. The comparison is made to Australian Joint Ore Reserve Committee (JORC) code, United States Department of Energy, and United Nations Framework Classification.

Table 2. Approximate correlation of term used in resources classification system [9]

| Identified Resources (Known Conventional Resources) | Undiscovered Resources (Undiscovered Conventional Resources) |
|-----------------------------------------------------|---------------------------------------------------------------|
| OCD-NEA/IAEA 2005 Reasonably Assured Resources (RAR) | Prognosticated (EAR-II) |
| Australia Demonstrated Inferred (EAR-I) | Speculative (speculative) |
| United States (DOE) Measured Indicated | Undiscovered |
| UNFC Reasonably assured Estimated additional | G1+G2 |
| | G3 |
| | Speculative |

The description of uranium resources in Indonesia will be describe based on characteristic of deposit and potential production, which is conventional and unconventional. Conventional resources are defined as “resources from which uranium is recoverable as a primary product, a co-product or an important by-product, while unconventional resources are resources from which uranium is only recoverable as a minor by-product” [10].

2.1. Conventional Resources

Uranium as a conventional resource found as metamorphic, volcanic, and sandstone deposit in Indonesia (Table 3 and Fig.1). In West Kalimantan, Kalan is the most important uranium mineralization area. Geographically it is located in up-stream part of Kalan River. Beside Kalan also there is Iban, Nanga Kepayang, and Ella Hilir. Kalan is situated in the northern margin of the Schwaner Mountains, Kalan geologically consists of Pinoh Metamorphic Group (PMG) rocks that were intruded by later granitic rocks of Sepauk Tonalite and Sukadana Granite in some parts. The Protolith of the Pinoh Metamorphic was the volcanogenic sediments that suggested to be formed during subduction at the Paleo-Pacific margin after collision of South West Borneo to Sundaland in Early Cretaceous (130 Ma) [11].
The uranium hosting Paleozoic Kalan Basin is located some 300 km ESE of Pontianak, the capital city of west Kalimantan. The basin fill consists largely of fine-grained, variably, epi to mesozonally metamorphosed volcano-sedimentary strata, which are separated into two series, an upper series, about 3,000–4,000 m thick, comprises metamorphosed sedimentary, volcano-sedimentary, and volcanic rocks of relatively monotonous nature and fine grain size, and the Lower Series is dominated by metapelite and metasiltstone of amphibolite grade facies with biotite, andalusite, cordierite, and sillimanite [9], [12]. According to IAEA geological classification of uranium deposit, the Kalan is included in metamorphic type of deposit [7], [13].

General stratigraphy, Kalan is divided into 5 units, which are lower series of volcano sedimentary, Rabau quartzite, upper Kalan volcano sedimentary, Amir Engkala felsic volcanic, and Bukitbiru meta-argillite [14], [15]. The most significant resources are located in Kalan Hulu volcanic sediment which is sector of Eko-Remaja, Lembah Hitam, and Lemajung.

Eko-Remaja and Lembah Hitam located close to each other, separated only by Kalan River. Intensive exploration activity in Kalan is focussed in both of these sectors; include more than 33,000 m of coring and non-coring drilling and also supported by exploration tunnel of 618 m length in Eko-Remaja.

Host rock of mineralization is metasiltstone and metapelite schistose, as interlayer in sterile rock metapelite Jeronang. Thickness of host rock is 80–100 m, with mineralization is controlled by structural opening, tectonic breccia, and some is in schistose layer [14]. Another study on mineralization control in the Eko-Remaja tunnel, it is first brittle deformation resulting open-mode fractures and schistosity planes that later filled by U-rich solution forming U veins, veinlets and breccia mineralization. The ductile deformation observed from N 70° E fold plunging 30° NE that generate schistosity plane dipping 70-80° relatively to the north [16], [17]. Resources of Eko Remaja is 3,220 in Reasonably Assured category [14], [18]. Lembah Hitam has almost the same host rock and mineralization style with Eko-Remaja, and has total resources of 1,994 tons U in Reasonably Assured category. Another same type of host rock and mineralization style is Lemajung sector, located 3 km NE from Eko-Remaja sector. More than 12,000 m exploration drilling has been done in this sector. Uranium resources in Lemajung is 769 ton U in Reasonably Assured category [19], [20].

Others important sector in Kalan is Rabau. Stratigraphically it is composed of Quartzite Rabau, with uranium mineralization in favourable rock of quartzite micro biotite and also controlled by tectonic plane. Total of 33 drillholes with total run of more than 4,700 m has been done in the area. Total resources in Rabau is 268 ton U with reasonably assured category [15], [21]. Another sector with identified uranium resources in Kalan area is Kalan Ketungau, Rirang, Amir Engkala, Tanah Merah, Jeronang Hulu, Senut, and Sarana [14], [22], [23]. Some high grades uranium and rare earth element (REE) in Rirang boulder is geologically very interesting; it is hosted in monazite boulder. The chemical analysis of the boulder indicates high rare earth element which is up to 59%, high phosphate contents, low alumina and silica content in monazite type [24]-[26].

In Ella Ilir Area, Batubulan sector, West Kalimantan, uranium mineralisation is trending NW-SE with 1-30 cm thickness with a radiometric anomaly ranging from 250-15,000 cps, hosted in metapelite schistose and metatuff rocks. The mineralization present as boudinage vein with uraninite as the radioactive mineral, associated with quartz tourmaline, feldspar, pyrite, iron oxide and hematite. Resource estimation results of 458 tU as inferred category of resources [27].

In East Kalimantan, the volcanic rock of Nyaan and Kawat riolite in up-stream of Mahakam River are the host for the uranium deposit. Uranium is stratabound dominated or majorly controlled by lava flow, and some also effected by later tectonic and mobilization to open tectonic fracture. Uranium minerals are pitchblende and autunite. Uranium resources are 9,247 ton U in Kawat sector, and 5,890 ton U in Pahuq and Nyaan sectors [28], [29].

In Central Kalimantan, Darab area also hosted uranium on its metamorphic and granitic rocks. The mineralization is closed to contact as tectonic breccia filling and veins. Radioactive minerals in the mineralized rocks are uraninite, monazite, and probably thoriano-uraninite. Uranium resources are 528 ton U in inferred category [30]. Mentawa area hosted uranium in its quartzite rocks. Uranium mineralization associated with tourmaline, quartz and sulfide, lenses in form, and has the same direction with schistosity plane. Resources is 8,194 ton U in prognosticated category [9], [31].
Table 3. Conventional uranium resources in Indonesia

| No | Sector                        | Identified Resources | Undiscovered Resources |
|----|-------------------------------|----------------------|------------------------|
|    |                               | RAR | Inferred | Prognosticated | Speculative |
| 1  | Eko-Remaja                    | 3,220 | -       | -              | -           |
| 2  | Rabau                         | 249  | -       | -              | -           |
| 3  | PC-15 (Kalan Ketungau)        | 42   | -       | -              | -           |
| 4  | Rirang                        | 30   | -       | -              | -           |
| 5  | Lembah Hitam                  | 1,994 | -       | -              | -           |
| 6  | Lemajung                      | 769  | -       | -              | -           |
| 7  | Amir Engkala                  | 319  | 462     | -              | -           |
| 8  | Tanah Merah                   | 210  | -       | 525            | -           |
| 9  | Jeronang Hulu                 | -    | 775     | -              | -           |
| 10 | Semut                         | 197  | -       | -              | -           |
| 11 | Jumbang                       | -    | -       | 3,336          | -           |
| 12 | Prembang Kanan                | -    | -       | 206            | -           |
| 13 | Dendang Arai                  | -    | -       | 118            | -           |
| 14 | Bubu                          | -    | -       | 93             | -           |
| 15 | Ririt                         | -    | -       | 8              | -           |
| 16 | Sarana                        | -    | 775     | -              | -           |
| 17 | Batu Bulan (Ella Ilir)        | -    | 458     | -              | -           |
|    | **East Kalimantan**           |      |         |                |             |
| 18 | Kawat                         | -    | -       | 9,247          | -           |
| 19 | Paluq dan Nyaan               | -    | -       | 5,890          | -           |
|    | **Central Kalimantan**        |      |         |                |             |
| 20 | Mentawa                       | -    | -       | 8,194          | -           |
| 21 | Darab                         | -    | 528     | -              | -           |
|    | **West Sulawesi**             |      |         |                |             |
| 22 | Salumati, Takandeang          | -    | 165     | 2,562          | -           |
| 23 | Rantedunia. Takandeang        | -    | 56      | -              | -           |
| 24 | Taan                          | -    | 431     | -              | -           |
| 25 | Hulu Mamuju                   | -    | -       | 1,096          | -           |
| 26 | Ampalas                       | -    | -       | 6,017          | -           |
|    | **North Sumatera**            |      |         |                |             |
| 27 | Aloban, Sibolga               | -    | 415     | -              | -           |
|    | **TOTAL**                     | 7,031 | 4,065 | 30,179        | 7,113       |

In Mamuju, West Sulawesi, first high dose rate radiation reported in 2007 when regional dose rate mapping took place. In 2012 data confirmation is conducted. Geologically, the area with the high radiation dose rate can be localized in geological Formation of Adang Volcanic. This formation is composed of alkaline volcanic rocks with basic to intermediates composition, and result of several volcanic events. Ever since 2013, the area has been intensively explored to identify uranium, thorium and other potential co and by-product elements. In 2015, first drilling activities were carried out in the Botteng, Takandeang, and Taan Sectors. A total of 21 boreholes were drilled for a total of 1,600 m. In 2019, the drilling continued in Ahu and Takandeang Sectors with total 6 boreholes and 750 m total depth. Resources estimated in Salumati are 165 tU in inferred category and 2,562 tU in prognosticated category. In Rantedunia Sector, uranium is estimated as 56 tU, while in Taan Sector, resources is estimated as 431 tU in inferred category. [5], [32]–[34]. Radioactive mineral identified in the area until now is thorite [35], davidite, thorianite, gummite, and autunite [36]. Higher concentration of thorium and rare earth are also typical on alkaline rocks, and could allow benefit development of this area. Hulu Mamuju Sector probably the most interesting target where the highest grade of uranium, thorium, and rare earth element found in the region. Nevertheless, despite the accessibility and steep
morphology feature, only limited radiometric and geological mapping, and radon survey could be conducted. The uranium resources in Hulu Mamuju and Ampalas Sectors are estimated 1,096 tU and 6,017 tU respectively as undiscovered speculative resources.

In North Sumatera, 22 drillholes have been conducted to characterize uranium mineralization in the Aloban sector. Uranium deposit located in the small localized intra-basin sediment which is restricted by a normal fault from surrounding granitic rocks. Uranium dominantly is absorbed by organic material in fine grains sediment, and formed the black shale type of deposit, while also in the interbedded sandstone and conglomerate, some anomaly also present. Uranium mineral is uraninite, carnitite, and coffinite. Resources estimated as 415 tU in Inferred category [37], [38].

2.2. Unconventional Resources

Uranium as unconventional resources dominated in monazite as by-product of tin and zircon mining (Table 4 and Fig. 1). In Semelangan, West Kalimantan, area of potential deposit is distributed in drainage area of Pawan, Tulak, and Laur River of more than 25,000 Ha area. S-type Sukadana granite is identified as source rock of this deposit. Resource in the area estimated 624 tU in Prognosticated category [13], [39]. In Central Kalimantan, Katingan has also the same condition as in Ketapang. The monazite is present as by-product of zircon mining as the main product of mine. Resources are estimated 485 tU in prognosticated category.

Bangka and Belitung are dominated the resources of uranium of unconventional deposit. Several limited surface explorations are done in the islands, which is geological and radiometric mapping, and heavy mineral geochemistry. Relatively simple geological setting, simple mining method, and high economic value of placer deposit brought so many interests of tin mining in the island. Radioactive mineral as by-product of tin mining is dominated by monazite and scarce of xenotime. Speculative resources in Bangka-Belitung are estimated 21,792 tU. Prognosticated resources is in Bangka Selatan 293 tU, in Bangka Tengah and Pangkalpinang (PKP) 263 tU, in Tumbang Rusa 415 tU, and in Cerucuk Belitung is 66 tU [40], [41]. Bangka Island is estimated as 2,407 tU.

Uranium in Singkep, is associated in the same tin-belt with Bangka-Belitung and other Riau islands. Monazite present also as by-product of tin mining. Resources are estimated 1,100 tU in the prognosticated category. Distribution of uranium (and thorium) resources, of both discovered and discovered resources category, can be seen in Figure 1.

Table 4. Unconventional Uranium Resources

| No | Sektor | Identified Resources | Undiscovered Resources |
|----|--------|-----------------------|------------------------|
|    |        | RAR | Inferred | Prognosticated | Speculative |
| West Kalimantan | 1 | Semelangan | - | - | 624 | - |
| Central Kalimantan | 2 | Katingan | - | - | 485 | - |
| Tin Belt | 3 | Bangka-Belitung | - | - | - | 21,792 |
|        | 4 | Bangka Selatan | - | - | 293 | - |
|        | 5 | Bangka Tengah & PKP | - | - | 263 | - |
|        | 6 | Tumbang Rusa | - | - | 415 | - |
|        | 7 | Cerucuk, Belitung | - | - | 66 | - |
|        | 8 | Bangka | 2,407 | - | - | - |
|        | 9 | Singkep | - | - | 1,100 | - |
| TOTAL | | 2,407 | - | 3,246 | 21,792 |
3. Conclusion

Uranium exploration had been conducted for more than 50 years to support nuclear power plant program in Indonesia. There are several prospect areas for uranium deposit and been intensively explored to support the nuclear fuel. Uranium resources are grouped into identified and undiscovered resources from their exploration status. The resources in these categories are 13,503 tU and 62,330 tU respectively. Based on characteristic of deposit and potential production, the resources are grouped into conventional and unconventional resources. The resources in these categories are 48,388 tU and 27,445 tU respectively. Total uranium resources are 75,833 tU in all categories. Exploration programs still continuous in some prospect Area in Indonesia. The result of uranium resources should be developed to increase the classification of resources and conducting the feasibility study to increase the resources to reserve classification. The exploration, deposit, and resources are the key to ensure the readiness of developing nuclear power plants with uranium fuel in Indonesia.

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