Uranium and thorium production projections in Turkey

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Abstract – Turkey committed to a long-term nuclear power program of 9200 MWe by 2030, and an additional 4800 MWe before 2050. This implies at least 2000 tonnes of uranium metal per year (tU/a) demand for the first phase of the program. Turkey's identified uranium resources especially in Western and Central Anatolia (8000 tU, as of 2013) are not sufficient to meet this demand. Nevertheless it is expected that new discoveries will be made by introducing a prospection program in promising areas and increasing the size of the existing deposits by using new drilling techniques.

Meantime preparatory works for uranium production from the largest uranium deposit in the country are about to be finalized and it is expected that 385 tU/a will be produced using the in-situ recovery (ISL) technique, and uranium recovery methods have alreadybeen experimented and established for other deposits as well.

Turkey has large amount of thorium resources (380 000 t ThO_2) mainly associated to rare earth oxide ores, at Eskisehir (100 km W of Ankara) and Burdur (150 km N of Antalya). These deposits have been identified as economically recoverable rare earth resources and thorium will be recovered as a by-product. Utilization of thorium fuel cycle in the planned nuclear power plants is under evaluation.

Uranium can also be recovered from one of these rare earth deposits (Burdur-Isparta) in addition to thorium, titanium, zirconium,etc.

In this paper a general review of uranium and thorium resources will be given including recent developments, as well as envisaged recovery techniques for both valuable elements.

I. INTRODUCTION

The construction of a nuclear power plant (NPP) has been considered in Turkey since the 1970's, but mainly due to the financial constraints, as well as lack of necessary infrastructure and trained technical personnel this project has always been postponed by the successive governments. Since 2000, as a consequence of the relatively high economic growth, rising energy demand and dependence on increasing energy imports (natural gas, coal) Turkey hasmoved once again to the advanced planning of construction of threenuclear power plants in the mid-term.

The first NPP (4 VVER-1200 units) will be constructed at the Mediterranean Akkuyu site (430 km E ofAntalya) by Rusatom. According to an intergovernmental agreement (IGA) between th Russian Federation and Turkey (July 2010), the project company will not only be responsible for the construction, but also for the supply of the nuclear fuel and waste management. In this context Rusatom has expressed an intention to build a Fuel Fabrication Plant in Turkey.

The second NPP of a total capacity of 4800 MWe (4 1200 MWe Atmea-1units) is planned to be built at Sinop (330 km NE of Ankara) on the Black Sea coast by Mitsubishi/Areva/Itochu/GDF-Suez consortium. Turkish governmental electricity production utility EÜAŞ will also be included in this project by taking 35% stake in theproject company. The IGA has recently been ratified (1st of April, 2015) in Turkish Parliament.

For the third NPP there are two proposed sites, both on the Black Sea coast. But the type of reactors and the installed capacity have not yet declared, though negotiations are continuing a Turkish electricity utility and a Chinese nuclear company and Westinghouse

However there are strong intentions and planning for nuclear fuel cycle activities to be undertaken by the Turkishside, among other services such as the operation and maintenanceof nuclear reactors.

It is worth noting that there are serious projections both in Government and in private sector for the utilization of thorium fuel cycle in the conventional nuclear reactors and for developing efforts of the Molten Salt Reactor technology with thorium fuel. In the Strategic Plan for 2015-2019 of the Ministry of Energy and Natural Resources R&D activities on Th fuel utilization are encouraged and as a forward step a National Workshop for Th Fuelled Reactors has been organized by the Ministry in early February of this year, bringing together all involved parties.

In this context prospection for the discovery of new uranium deposits as well as expansion of existing reserves have gained importance during the last years.

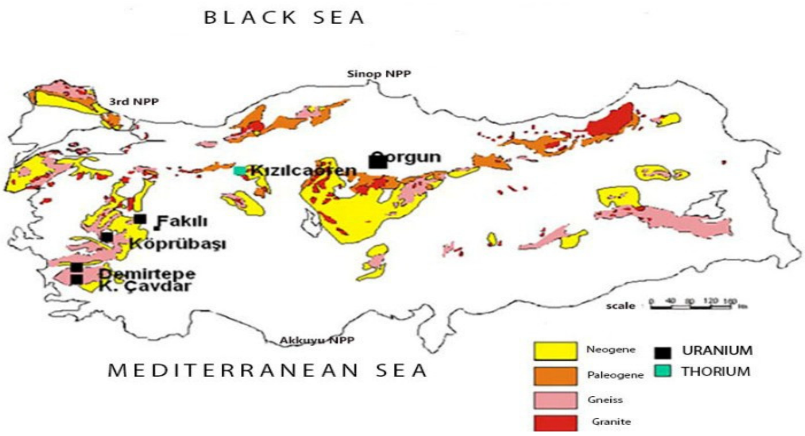

Fig. 1. Turkey's uranium and thorium deposits (MTA)

II. URANIUM IN TURKEY

According to nuclear power program necessities, exploration for uranium began in the late 1950's in sedimentary rocks and mainly autunite and torbernite mineralization has been found in the Western Anatolia.

Uranium exploration activities have always been conducted by a State institution (MTA), but as a consequenceof the different government priorities activities were not consistentover the decades.

Meantime, some improvements have put into effect in the mining law (2010) to encourage the participation of private uraniumexploration and mining companies, and it is expectedthat this new step will help to increase uranium resources inTurkey.

II.A. Uranium resources

As a result of these exploration activities till mid-1980's, a total of 7 740 tU in situ resourceswere identified in the Manisa-Köprübaşı (2 419 tU), Uşak-Eşme (415 tU), Aydın-Koçarlı (176 tU), Aydın-Söke (1 466 tU) and Yozgat-Sorgun (3 265 tU) regions [1].

After a long pause, exploration activities were restarted after 2005 by the *General Directorate of Mineral Research and Exploration* (MTA) in order to find new deposits in promising areas, as well as to enhance resource evaluation in already existing deposits. After completion of the exploration activities in Yozgat-Sorgun area driven by MTA, a private company (ADUR, 100% owned by Anatolia Energy) acquired the exploration licenses and drilled 51 boreholes for over 7 300 m at the end of 2013. These intense works have increased uranium resources (measured, indicated and inferred) up to 5200 tU withan average grade of % 0,0981 U [2].

The increase of Yozgat-Sorgun uranium resources to 5200 tU from 3 265 t U and newly explored deposits in Köprübaşı, Nevşehir and Aydın areas, one canconclude that by introducing new exploration techniques and drilling programs uranium resources of Turkey would largely exceed 10 000 tU as reasonably assured resources in the near future, with recovery costs estimated in 40-80 USD/kgU (100-200 USD/lb U_3O_8) category.

II.B. Uranium production estimations

Yozgat-Sorgun (Temrezli) uranium resource, owned by Adur (Anatolia Energy) is the best studied project for uranium production and the company has recently announced that they are ready to produce uranium in the 2nd half of 2016 [3].

Recovery leach test work was performed on three samples of Temrezli material by using preliminary bottle-roll leach test. These samples were selected from a larger batch of five composite samples provided by Adur.

For the acid leach test, samples were subjected to 1.5 pH sulfuric acid for 48 hours at ambient temperature. Ferric sulfate was added as the oxidizing agent.

The alkaline leach conditions consisted of 40 g/L carbonate and 10 g/L bicarbonate at a pH of 10, and sodium hypochlorite as an oxidant. The alkaline leach was extended to 120 hours as leach rates were expected to be lower than the acid leach.

In an acidic environment, the leach rate is quite fast with up to 93 percent of the uranium extracted within 50 hours and 85 percent within 4 hours, while extraction of other elements appears low with less than 20 percent of the iron and 10 percent of the calcium leached.

High extraction percentages of manganese and copper were observed; however, these elements were of low grade in the sample and therefore did not represent a significant contaminant in the leach solution. Acid consumption was low at 42-63 kg of acid/tonne of ore.

In an alkali environment, the leach rate was less rapid but still achieved uranium extraction of approximately 80-90 percent within 120 hours and 70-80 percent within 50 hours, while extraction of other elements was very low due to selective uranium leaching. Reagent consumption during alkali leaching was low.

Column leach testing was also performed on samples from the Project area (2012, Jan.), with a carbonate solution with a pH of ten. The laboratory maintained head on the column to provide a flow velocity of 0.2 m/day and recorded redox potential (Eh), pH, and free carbonate as well as a solution assay from the discharge at specific time increments. Total leach time was 168 hours.

Method selection: the mineralogical structure of the ore body and hydrogeology of the deposit as well as the encouraging results of the tests have demonstrated that in-situ recovery (ISL) would be feasible and profitable for the extraction of uranium. Another reason for Anatolia's method of choice for the Temrezli uranium deposit is that ISL has environmental, safety, and economic advantages compared to conventional uranium extraction methods.

Another important point for choosing ISL relays on that it does not create hazardous tailings and provides containment for all radioactive material, reducing the risk of exposure to workers and the general public.

All necessary underground hydrological measurements have already been accomplished and Environmental and Social Impacts Assessment (ESIA) documents are under way.

Recovery of uranium from the pregnant mining solution containing dissolved uranium complexes will be accomplished at the Central Processing Plant (CPP). Processes used at the CPP to recover uranium will include the following circuits:

- Resin Loading (IX circuit);
- Resin Elution;
- Uranium Precipitation; and
- Uranium Product Washing, Drying and Packaging.

Planned production is 385 tU/year [4].

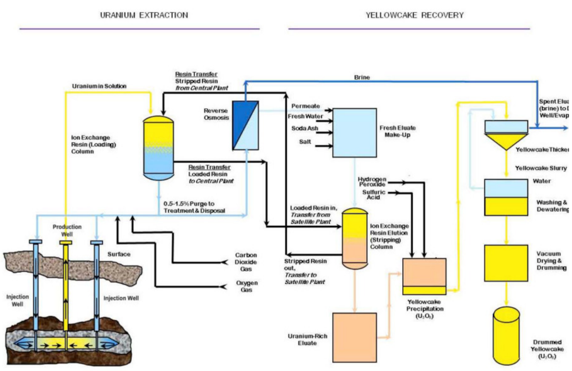

Fig. 2. Yozgat-Temrezli uranium ISR processing plant

Manisa-Köprübaşı uranium resource is owned by *Eti Mine Works General Management* (Eti Maden –State owned company) which is also responsible for another fiveuranium sites in Turkey.

The Manisa-Köprübaşı area hosts two major uranium deposits, *Kasar* and *Taşharman*, each representing nearly the half of the whole reserve (~1200 tU/each deposit). The Taşharman deposit is located 175 km NEof Izmir (3rd largest city of Turkey) and Kasar takes placeat 25 km SW of Taşharman. Uranium mineralization is autunite in both deposits, but Taşharman ore contains about 0,05%U and 8% P_2O_5 (phosphate) which rendersdifficult the recovery of uranium due of high consumptionof acid and subsequent separation of uranium from leach solution.

On the other hand, the Kasar deposit with 0,05-0,07% U content has practically no phosphate and dissolution of uranium in diluted acidic solutions is relatively easy and acid consumption is low.

Method selection: the mineralogical structure, low uranium content and the closeness of the ore body to the surface led experts to choose open pit mining, followed by heap leaching.

Recovery leach test works began in early 1970's in MTA laboratories for Kasar deposit and in Çekmece (İstanbul) Nuclear Research and Training Centre (ÇNAEM) for Taşharman and Kasar deposits, using the representative samples provided by MTA.

Column leach tests for Kasar uranium ore gave a high recovery of uranium (>90%) with acid consumption of 25 kg H_2SO_4/ton of ore. Based on these parameters a pilot plant has been established in Köprübaşı area by MTA and approximately 1.5 ton of U concentrate (as yellow cake) has been produced before the closure of the plant in early 1980's. Heap leaching was the recovery method of uranium in the pilot plant and subsequent separation has been realized by amine solvent extraction, followed by uranium precipitation with magnesium hydroxide.

Taşharman ore processing by heap leaching technique had been deeply investigated by changing parameters such as acid type (HCl, HNO_3, H_2SO_4), acid concentration, percolation condition (continuous or discontinuous), flowrate, particle size, utilization of surfactant materials, etc. Results show that 80% uranium recovery can be obtained by consumptionof 100 kg HCl/ton of ore, versus 160 kg H_2SO_4/ton of ore.

The ideal flowrate was 100L/h/m^2 in discontinuous percolation system with acid solutions having different acid concentrations and by selecting special particle size (-25.4mm +0.6 mm).

In last series of column tests a mixture of two deposits (Kasar 50% and Taşharman 50% by weight) were studied, and finally it has been found 85% uranium recovery, for an acid consumption of 57 kgHCl/ton of ore mixture and 1.5 m^3 water/ton mixture.

Recovery of uranium from pregnant leach solutions which contains nearly 0.65 gU/L and 16.4 gP_2O_5/L could be suitable for solvent extraction using phosphoric esters (e.g. DDPA) but in these tests selective precipitation had been chosen after reducing U^{+6} to U^{+4} by using strong reductants such as sodium dithionite. The separation rate of uranium had been found as high as 97.5% and uranium content of the concentrate (mainly uranium-IV phosphate) was 37%. A selective solid-liquid extraction had been applied to the dried concentrate by using an organic solvent saturated with HCl.

It is indicated that a final product in form of $UF_4.nH_2O$ (which met nearly the nuclear purity requirements) with very high recovery yield could be obtained after this step [5].

III. THORIUM IN TURKEY

In the early 1960's during uranium exploration studies conducted by MTA, radioactive anomalies have been identified at **Eskişehir-Beylikova** location, which is about 150 km W of Ankara. After analysis of several drill samples it was shown that the anomalies were the result of thorium but not uranium.

III.A. Thorium (and Rare Earth Elements) resources

Expanded researches during the 1970's and 1980's in the area proved 30.4 million tons of ore resources with an average content of 37.4% calcium fluorite, 31% barite, 3.14-5.2% REO (Lanthanide oxides) and 0.21% ThO_2. Mineralization of REEs (rare earth elements) and Th is mainly bastnaesite. But in recent years the ambitious drilling program carried out by Eti Maden (owner of the site) is on the way to double the inferred resources for both REEs and Th.

REEs and Th content of the Eskişehir-Beylikova ore is shown in Table I.

TABLE I

Distribution of REEs and Th in Eskişehir in-situ deposit

Elements	Content %
Y	0,77
La	32,20
Ce	41,00
Pr	3,50
Nd	10,51
Sm	2,43
Eu	0,29
Gd	1,85
Tb	0,39
Dy	0,99
Ho	0,37
Er	0,06
Tm	0,24
Yb	1,03
Lu	0,25
Th	4,12
Total REE+Th	100,00

These results made the Eskişehir-Beylikova deposit, one of the largest thorium deposits in the world and an important resource for REEs with nearly 350 000 tons of Th and 1 000 000 tons of REEs.

Another Th (as well as U) resource associated to REEs has been discovered by a private company **AMR Madencilik A.Ş.** (AMR Mining Ltd.) at Burdur-Çanaklı (**Aksu-Diamas Project**) area during a diamond exploration.

TABLE II
AMR Main Resources

Location	**Tonnes (million)**	**In-situ REEs grade**	**In-situ REE (tonnes)**	**In-situ Th (tonnes)**	**In-situ U (tonne**
Çanaklı-I	80	687	54 960	3 440	678
Çanaklı-II	414	575	238 050	13 810	2
Total	*494*		***293 010***	***17 250***	***3***

Therefore, there are another four potential locations in the same area (namely Çobanisa, Kuyubaşı, Kuzca, and Kurucaova) with nearly 500 million tons of resources, having approximately the same grades of REEs, Th and U as the Çanaklı-II location. With these potential resources *the total REEs reserves of the whole area could exceed 500 000 tonnes, total thorium 35 000 tonnes and total uranium 7 000 tonnes.*

This complex ore contains also zirconium and titanium in appreciable amounts. The REE mineralization is the allanite type in which thorium and uranium are included with silicate bounds.

TABLE III

Distribution of REEs, Th and U in AMR Çanaklı deposit

Elements	Content %
Y	4,34
La	23,05
Ce	39,86
Pr	4,07
Nd	14,10
Sm	2,03
Eu	0,50
Gd	1,27
Tb	0,16
Dy	0,80
Ho	0,14
Er	0,39
Tm	0,06
Yb	0,38
Lu	0,06
Th	6,10
U	1,22
Sc	1,49
Total (REE+Th+U+Sc)	100

MTA has recently informed that it prepares a new exploration program for thorium, associated or not to the

REEs, in some promising areas such as Malatya-Hekimhan (E of Ankara).

III.B. Thorium (and Rare Earth Elements) production estimates

Despite several studies on the **Eskişehir-Beylikova complex ore** both in laboratory and pilot plant scales have been conducted since 1974 in order to separate and recover Th, REEs, calcium fluoride and barium sulphate by physical beneficiation works (e.g. magnetic, gravimetric separations, flotation, etc.), however none have been found effective in respect to recovery yields (for any of the valuable species in the ore). Th and its radioactive daughters were found in every enriched part, due to the disseminated character of thorium.

The most recent studies started at 2004 were oriented to separate firstly REEs together with thorium, and then recover calcium fluorite and barite separately by applying physical enrichment techniques (gravity, flotation) from REEs and Th free solid material.

This new approach has been tested in MTA and ÇNAEM laboratories and found very promising because it was possible to recover REEs and Th with respective recovery yields of 76.4% and 78.9% (from run-of-mine to final product), barite 84% and calcium fluorite 68%. Th was separated from REEs oxalate concentrate in the early stages of the process with a recovery yield of 99%. Hence, there was no contamination of Th in the final REE concentrate.

Th is separated by using two subsequent steps: **firstly**, after dissolving REEs+Th hydroxides in HCl, following metathesis of oxalate concentrate with concentrated sodium hydroxide and the Th is easily separated by adjusting pH of the solution (99% separation yield); **secondly**, raw Th hydroxide is dissolved in nitric acid and Th is precipitated by hydrogen peroxide leaving most of REEs in the solution which are recycled to the main stream [6]. For a predicted production of 5 000 tons of REEs per year, 120-150 tons of ThO_2 will be produced as a by-product.

On the other hand, complex ore of the **Burdur-Çanaklı area** has been thoroughly investigated and studied since 2007 by **AMR Madencilik** and it is found that the valuable minerals grades in the ore body in horizontal and vertical directions is practically the same and the mineralization conserves its uniformity.

It is also shown that REEs, titanium, zirconium and other valuable minerals (U and Th) are readily concentrated by gravity and magnetic separation and flotation into a relatively high grade concentrate (up to 2 - 2.5% for REEs, 0.15% Th and 0.03%U), without prior crushing and grinding operations. During the physical beneficiation process a high-grade magnetite has been separating.

Flotation concentrate must be cracked by mixing with NaOH at relatively high temperature to get frit of concentrate which is dissolved in HCl. The chloride solution after filtration is treated by solvent extraction to separate iron chloride. The remaining solution is treated by phthalic acid to precipitate zirconium (+hafnium), titanium and most of uranium.

From separated zirconium, uranium and titanium concentrate, zirconium and uranium are extracted by TBP-SX and U is produced by selective stripping from organic phase.

REEs and Th are co-precipitated with oxalic acid, followed by Th separation by using the peroxide method. From the remaining REE concentrate, light REEs such as Ce, La and Nd+Pr could be separated individually and the heavy REE concentrate is to be sent to a REEs separation and refinery plant.

AMR Madencilik envisages two production phases: in **phase-I**, there will be 800 tons/hour and in **phase-II** (*full capacity*) 3800 tons/hour of run-of-mine would be introduced to the physical concentration plant and the product quantities at the end of the whole production cycle will be as follows for two operational phases [7]:

TiO_2: 5500 t/y and 25 400 t/y
ZrO_2: 890 t/y and 3 300 t/y
La_2O_3 : 425 t/y and 1730 t/y
Ce_2O_3 : 650 t/y and 2500 t/y
(Nd+Pr)Ox : 290 t/y and 1120 t/y
HREO : 115 t/y and 470 t/y
Th: 79 t/y and 377 t/y
U: 15 t/y and 72 t/y.

(*Magnetite and iron oxide products are not figured here*.)

IV. CONCLUSIONS

Actual progress shows that mining for radioactive materials will be undertaken within the general mining activities of Turkey in the near future. The uranium exploration and consequently its production will increase parallel with the implementation of nuclear in the country and privatization of radioactive ore mining. REE production will inevitably start off the production of appreciable amounts of thorium and a limited production of uranium (in the case of Aksu-Diamas project). Uranium is relatively easier to market, but thorium should be stocked until new utilization areas render it a commercial commodity. Hence Turkey's governmental and private sectors are progressively interesting for energy production systems utilizing thorium fuel cycle.

NOMENCLATURE

EÜAŞ: Electricity Production Company of Turkey
MTA: General Directorate of Mineral Research and Exploration, Turkey.
Eti Maden: Eti Mine Works General Management.
REE: Rare Earth Element(s), lanthanide(s).
REO: Rare Earth Oxides, lanthanides.

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