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# Phosphate Rocks and Nuclear Proliferation

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**ABSTRACT**

Phosphate rocks are predominantly mined for fertilizer production. However, they also contain considerable amounts of accompanying natural uranium that can exceed concentrations found at commercial uranium mines. Extracting uranium from phosphate rocks during fertilizer production is a technically mature process; it was used on an industrial scale in the United States and elsewhere before decreasing uranium prices made this practice unprofitable in the 1990s. Soon, technical improvements, potentially rising uranium prices, and anticipated environmental regulations may make uranium extraction from phosphates profitable again in the United States and emerging phosphate rock mining centers in Northern Africa and the Middle East. Extracting uranium during phosphate fertilizer production is desirable in a way that otherwise lost resources are conserved and fertilizers with reduced radiotoxic heavy metal content are produced. Phosphate rocks have also been subject to clandestine uranium acquisition. In this work, the relevance of unconventional uranium resources from phosphate rocks is reviewed. A brief overview of the extraction process, a list of the required materials, and a very simple estimation of the amounts of uranium that could be extracted using a container-sized pilot plant which can be integrated into existing fertilizer plants is provided. Lastly, past known unreported uranium extraction activities from phosphate rocks are discussed.

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## Introduction

The acquisition of plutonium or highly enriched uranium (HEU) is traditionally understood as the hardest part of the nuclear explosive device production process.[1] The plutonium route is not further discussed here. HEU is produced through enrichment of natural uranium. This challenging process was traditionally associated with relatively large intelligence signatures (e.g., large energy and space requirements for gaseous diffusion and gas centrifuges), and is arguably still the main barrier to nuclear weapons production capability. These large industrial

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facilities are an important observable indicator that an actor is pursuing nuclear weapons development.[2]

In comparison, uranium acquisition attracts relatively little attention, e.g., uranium ore concentrate (UOC) is not monitored by the Nuclear Suppliers Group (NSG) or International Atomic Energy Agency (IAEA) safeguards.[3] There is little concern as most UOC sales are mostly to NSG members (although not necessarily from NSG-states, e.g., Namibia and Niger are relevant uranium suppliers).[4] Nevertheless, undeclared or clandestine accumulation of uranium stocks may significantly facilitate proliferation. An appropriate level of transparency of uranium production by any mining process is therefore relevant to nonproliferation efforts.

All conventional uranium production (mining or extraction alike) should be reported to IAEA under its comprehensive safeguards agreement (INFCIRC/153) and additional protocol (INFCIRC/540). An increasing number of actors are considering uranium extraction from unconventional resources. Forcing states to report uranium extraction from unconventional resources presents challenges to IAEA. Some countries, for instance, do not report accompanying uranium as they fear compromising the value of the primary ore, or they are simply not aware of byproduct uranium extraction operations taking place as they are, due to their relatively little economic importance sometimes not (directly) declared by mining companies.

Among these unconventional resources phosphate rocks are of prime importance due to the relatively large concentration of accompanying uranium and the technical maturity of the uranium extraction process. Phosphate rock production is expected to increase from 223 million tons in 2015 to 255 million tons in 2019, while phosphate rock processing plants may triple in capacity by 2018.[5] Uranium extraction plants can be relatively easy to integrate into existing phosphate rock processing plants and may benefit from the available infrastructure. As a result of the global abundance and the large global trade volumes of phosphate rocks, it is unlikely that IAEA or any other organization will have the capacity to monitor global phosphate rock trading and processing.

It has been argued though that since the number of countries proficient in uranium enrichment or other technologies critical from the non-proliferation standpoint has increased over time, additional measures, such as an introduction of nonproliferation regulations to the UOC market and particularly uranium extraction from unconventional resources, may be necessary.[6]

In this work the relevance of unconventional uranium resources from phosphate rocks is reviewed. A brief overview of the extraction process that includes a list of the required materials and a very simple estimation of the amounts of uranium that could be extracted using a container-sized pilot plant which can be integrated into existing fertilizer plants at different locations is provided. Lastly, past known unreported uranium extraction activities from phosphate rocks are discussed.

## Phosphate rocks—a relevant unconventional uranium source

The Nuclear Energy Department of the IAEA differentiates between conventional and unconventional uranium sources.[7] Among the various unconventional sources

mentioned (phosphate rocks, non-ferrous ores, carbonatite, black shale a,nd lignite) uranium from phosphate rocks is of predominant importance. Other unconventional sources (e.g., black shale and seawater) may become relevant at some point in the future.[8] The predominance of uranium from phosphate rocks among the unconventional resources may be explained by:

- The relatively high average and local concentrations of uranium found in phosphate rocks;
- The large quantities of uranium found in phosphate rocks globally;
- The technical maturity of extracting uranium from phosphate rocks during fertilizer production.

Extracting uranium from phosphate rocks is inexpensive when compared with other unconventional sources, particularly uranium extraction from seawater. Furthermore, otherwise lost uranium resources can be conserved and the amount of radiotoxic elements in the final fertilizer products can be significantly reduced by removing more than 90% of the accompanying uranium.[9] In addition to uranium, phosphate rocks contain several trace elements such as rare earth elements (REE) that can be extracted and sold as well.[10]

## Concentration of uranium in phosphate rocks

Phosphate rocks are naturally occurring mineral deposits which contain relatively high concentrations of phosphate minerals.[11] Uranium is an accompanying element in phosphate rocks. There are two major sources of phosphate rocks: sedimentary and igneous (magmatic) deposits.[12] Typically, deposits are of a single type and typically uranium concentrations are reported to be considerably higher in sedimentary deposits. About 80–90% of the world's phosphate production in the last ten years is estimated to derive from sedimentary sources.[13] Igneous deposits provided about 10–20% of the world's phosphate rock production during the last ten years with small additional quantities from excavated biogenic resources, largely bird and bat guano accumulations.[14] Worldwide average uranium concentrations in phosphate rocks range from 25–50 ppm with local deposits showing concentrations as high as 600 ppm.[15] In comparison, the average concentration of uranium in seawater is as low as 0.003 ppm.[16] It is after concentration in loaded sorbents that relevant uranium concentrations from seawater are available.[17] The Nuclear Energy Department of the IAEA recognizes ores with minimum concentrations of 300 ppm as uranium resources.[18] The World Nuclear Association (WNA) differentiates between (1) very high-grade uranium ores (>200,000 ppm), (2) high-grade uranium ores (>20,000 ppm), (3) low-grade uranium ores (>1,000 ppm) and (4) very low-grade uranium ores (>100 ppm)[19] as indicated in Table 1.

Average uranium concentrations in phosphate rock deposits in Algeria (Djebel Kouif, 100 ppm), Angola (Cabinda, 260 ppm), Brazil (Araxa, 182 ppm and Catalao, 220 ppm), Burkina Faso (Kodjari, 125 ppm), Egypt (Hamrawen, 110 ppm, Safaga, 120 ppm, and West Mahamid, 100 ppm), Israel (Arad, 150 ppm), Mali (Tilemsi, 123 ppm), Morocco (undifferentiated, 130 ppm), Tanzania (Minjingu, 390 ppm),

**Table 1.** Characterization of uranium ore (World Nuclear Association).

| | Concentration [ppm uranium] |
|---|---|
| Very high-grade uranium ore | >200,000 |
| High-grade uranium ore | >20,000 |
| Low-grade uranium ore | >1,000 |
| Very low-grade uranium ore | >100 |

United Sates (Central Florida, 141 ppm and Idaho, 107 ppm) as reported by van Kauwenbergh[20] are high enough to be labeled as "very low-grade uranium ores" and exceed the concentration of a number of very low-grade commercial uranium mines that are, for example, operated in Namibia.[21]

## Quantity of uranium in phosphate rocks

Overall phosphate rock reserves are concentrated in a few countries with deposits in Morocco (including Western Sahara) accounting for nearly three quarters of all material.[22] Phosphate rock resources are subject to active scientific discussion due to the importance of phosphate rocks for the world's food security.[23] Figure 1 provides an overview of global phosphate rock production and phosphate rock reserves by country in 2015 using data from the U.S. Geological Survey.[24]

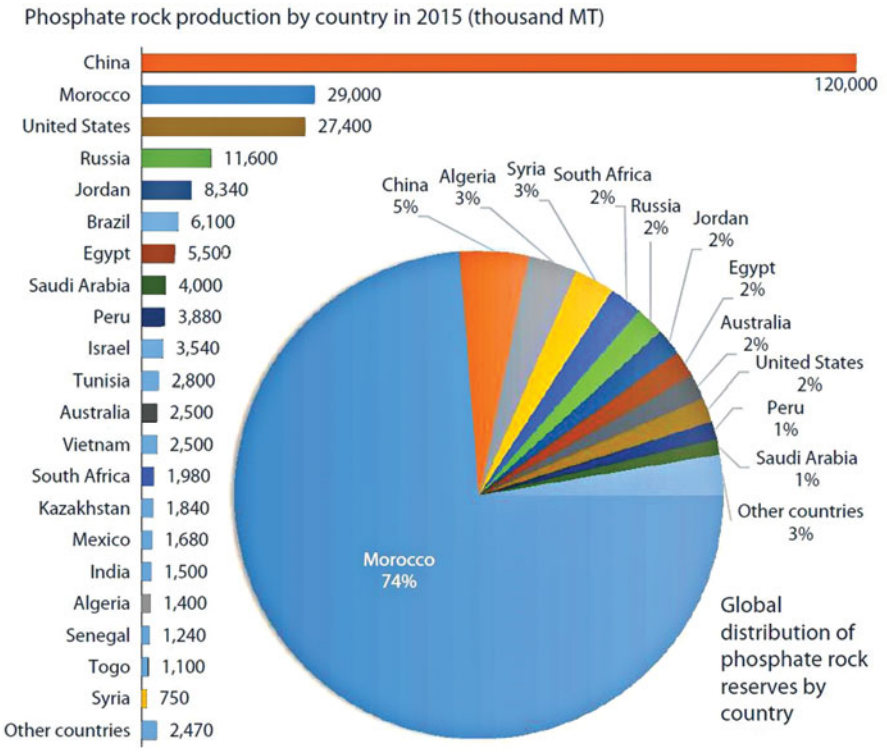


**Figure 1.** Global phosphate rock production (bar chart) and phosphate rock reserves (pie chart) in 2015 (U.S. Geological Survey).

The quantity of uranium in phosphate rocks is considerable. WNA reports that in addition to the 5.9 million metric tons (MT) of known recoverable uranium resources, 9–22 million MT may be found in phosphate rocks worldwide.[25] Ulrich et al. suggest similar amounts (5.7 million MT).[26] Gabriel et al.[27] estimate that slightly more than 15% of uranium required for peaceful purposes worldwide could come as a purified byproduct from phosphate fertilizer production and Kim et al.[28] further estimate that as of 2017, 10% of uranium required for peaceful purposes in the United States could be provided from the country's phosphate fertilizer production chain. The large quantities differentiate uranium from phosphate rocks from other unconventional uranium resources such as uranium from black shales that show similarly high uranium concentrations (20–500 ppm) but less significant overall quantities.[29]

## Past commercial extraction of uranium from phosphate rocks

The first industrial attempts to recover uranium from phosphate rocks started in Florida[30] and to the mid-1990s about 20% of uranium mined in the United States was a byproduct of phosphate rock processing.[31] Past attempts to recover uranium from wet phosphoric acid (WPA), an intermediate product in phosphate fertilizer production, can be divided into three waves ranging from the early 1950s to the early 1960s (first wave), the late 1970s to the mid-1990s (second wave) with the last commercial plant closing operation in 1999, and a third wave that may be a result of technically improved extraction techniques, rising uranium prices, and upcoming environmental regulations.

During the first wave (1951–1962) 17,150 MT uranium were recovered from phosphate rocks in the United States, mainly for defense purposes.[32] Rising uranium demand for commercial nuclear power and increasing prices in the 1970s led to a second larger wave resulting in plants being constructed and operated in Belgium, Canada, Iraq, Taiwan, and the United States.[33] It is estimated that some 20,000 MT uranium were recovered during this period. Other considerable uranium recoveries from phosphate rocks took place in the former Soviet Union. In Kazakhstan for instance 40,000 MT uranium (from 1970s to 1990s) were recovered from marine organic deposits (essentially concentrations of ancient fish bones with higher grades of uranium).[34] Table 2 provides a brief overview of industrial plants that extracted uranium for commercial purposes from WPA.[35,36]

Kim et al.[37] estimated that uranium prices as high as \$50/lb. $U_3O_8$ would make uranium extraction again profitable in the United States. This trend may be further enhanced by improvements in recovery techniques such as in ion exchange recovery and potential regulations for upper limits for uranium content in fertilizers.

## Wet phosphoric acid production and uranium recovery

Two primary phosphate rock processing methods: WPA and thermal acid processes can be differentiated. The WPA process is presently the most economical due to

**Table 2.** Commercial plants recovering uranium from wet phosphoric acid during the 1st and 2nd wave.

| | Country | Plant | Operating Period | Owner/ Operator | Process | Reported uranium extraction capacity [MT $U_3O_8$/year] | Reported uranium production [MT $U_3O_8$/year] |
|---|---|---|---|---|---|---|---|
| 1st wave (1951–1962)[a] | United States | Joliet, IL | 1951–1962 | Blockson Chemical Co. | Precipitation | 36 | — |
| | United States | Texas City, TX | 1952–1956 | Texas City Chemicals, Inc./Atomic Energy Commission | OPPA | 23 | — |
| | United States | Nichols, FL | 1954–1959 | Virginia-Carolina Chemical Corp./Atomic Energy Commission | — | — | — |
| | United States | IMCC Plant, Bonnie, FL | 1955–1961 | IMCC Intl. Minerals & Chemicals Corp. | OPPA | 36 | — |
| | United States | Tampa, FL | 1957–1961 | U.S. Phosphoric Products | OPPA | 73–163 | — |
| 2nd wave (1976–1999)[b] | United States | W.R. Grace Plant, Bartow, FL | 1976–1980 | W.R. Grace/URC Uranium Recovery | OPAP | 129–150 | 120–127 |
| | United States | Farmland, Pierce, FL | 1978–1981 | Farmland Industries/Wyoming Minerals Corporation | DEPA-TOPO | 181–204 | 137–163 |
| | United States | Uncle Sam, Convent, LA | 1978–1999 | Freeport Minerals | DEPA-TOPO | 313 | 265–345 |
| | United States | Riverview Plant, East Tampa, FL | 1979–1982 | Gardinier-Pechiney | OPPA | 163–193 | 163 |
| | United States | CF Industries, Bartow, FL | 1980–1985 | CFI/IMC | DEPA-TOPO | 272–286 | 218–254 |
| | United States | CF Industries, Plant City, FL | 1980–1992 | CFI/IMC | DEPA-TOPO | 272–286 | 231 |
| | United States | IMC, New Wales, FL | 1980–1992 | IMC | DEPA-TOPO | 313–340 | 289–317 |
| | Belgium | Engis, Liège | 1980–1998 | Prayon/ Union Minière and Umipray S.A. (joint-venture) | DEPA-TOPO | 59 | 50 |
| | Canada | WCFL, Calgary, AB | 1980–1981; 1983–1987 | Earth Sciences Extraction Co. & Urangesellschaft Canada Ltd. | OPAP; DEPA-TOPO | 45 | 42 |
| | Taiwan | China Phosphate, Lung Tan | 1981–1985 | Institute of Nuclear Research (NERI) | DEPA-TOPO | 12 | 10–12 |
| | United States | Sunshine Bridge, Donaldsville, LA | 1981–1998 | Agrico Chemical/Freeport Minerals | DEPA-TOPO | 191 | 162–196 |
| | Iraq | Al Qaim | 1984–1991 | SOM (Preyon/Mechim) | DEPA-TOPO | 103 | 54 |

a35

b36

high energy intensity of thermal processing. Phosphate rocks are usually concentrated before leaching. Depending on the nature of the gangue material[38] mixed with the phosphate rocks, simple techniques such as crushing, grinding and/or screening may be sufficient for extraction. In most cases, more advanced techniques such as flotation or calcination are required.[39] During WPA production the concentrated ore is leached with hydrochloric acid (Equation 1), nitric acid (Equation 2) or sulfuric acid (Equation 3).[40]

$$Ca_{10}(PO_4)_6F_2 + 20HCl \rightleftharpoons 6H_3PO_4 + 10CaCl_2 + 2HF \quad (1)$$

$$Ca_{10}(PO_4)_6F_2 + 20HNO_3 \rightleftharpoons 6H_3PO_4 + 10Ca(NO_3) + 2HF \quad (2)$$

$$Ca_{10}(PO_4)_6F_2 + 10(H_2SO_4 \bullet nH_2O) \rightleftharpoons 6H_3PO_4 + 10(CaSO_4 \bullet nH_2O)_s + 2HF \quad (3)$$

Presently, about three quarters of WPA is produced using sulfuric acid.[41] Uranium has traditionally been extracted from the pre-concentrated phosphoric acid as part of the WPA purification. Figure 2 provides a brief overview of the process and indicates at which point uranium can be extracted and further processed to yellow cake if desired. The advantage for commercial uranium extractors and potential proliferators alike is that uranium extraction units can be added to existing infrastructure. Since phosphoric acid is a liquid, only piping that results in little to no visible footprint is required.

It is worth noting that uranium extraction from WPA is today the most economical way to extract byproduct uranium. Less economic methods include extraction directly from phosphate rock,[42] merchant grade WPA or even final fertilizer products.

Mined phosphate rocks are concentrated in a beneficiation step to increase the phosphorous content. Concentrated phosphate rocks are digested in acid (most of the time sulfuric acid, $H_2SO_4$, is used) to produce phosphoric acid. Besides phosphoric acid, relatively large amounts of phosphogypsum (roughly 5 MT phosphogypsum per 1 MT phosphoric acid) accrue during the process. Phosphogypsum shows low levels of radioactivity that precludes its usage as a construction material.[43] In most cases phosphogypsum is currently stacked next to the processing plants. Most uranium (80–90%) ends up in the phosphoric acid stream. How much uranium is transferred to the WPA and phosphogypsum is ultimately dependent on the process conditions and feed material.[44]

Solvent extraction methods were the predominant methods of choice for extracting uranium during phosphoric acid purification. Solvent extraction is

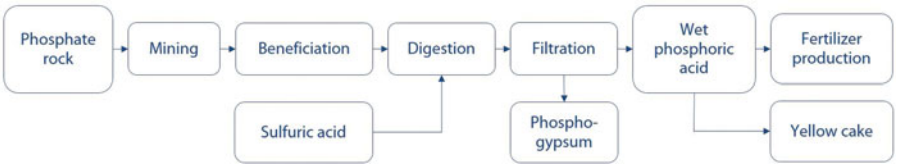


**Figure 2.** Brief overview of the WPA process with uranium extraction.

accomplished with some combination of di (2-ethylhexyl) phosphoric acid (DEPA, DEHPA or D2EHPA) and trioctyl phosphine oxide (TOPO), octyl phenyl acid phosphate (OPAP), octyl pyro phosphoric acid (OPPA) or tributyl phosphate (TBP). Beltrami et al.,[45] Bunus[46] and Singh et al.[47] provide comprehensive reviews of the different extraction processes used. Among these options the DEPA-TOPO or ORNL process developed at Oak Ridge National Laboratory was the most widely used extraction process.[48] The process was predominantly used for industrial purposes due to its stability, efficiency and selectivity.[49]

## Materials required for the DEPA-TOPO process

The basic DEPA-TOPO process requires little material input. Hurst et al.[50] provided a list of materials required for the DEPA-TOPO process for an economic assessment. The quantities needed to extract 1 g $U_3O_8$ as well as the quantities needed to extract a "significant quantity" (10 MT) natural uranium are provided in Table 3. None of the listed materials is considered a dual-use item by the Wassenaar Arrangement,[51] or the Australia Group Export Control list.[52]

## Possibilities of small scale uranium extraction

In addition to the commercial plant operations listed in Table 3 several pilot plants using different extraction techniques were operated around the globe. Urtek LLC, for example, developed an alternative technique, based on ion exchange, to commonly solvent extraction processes such as the DEPA-TOPO process that promises lower costs and higher recovery rates and is designed to be integrated into existing phosphoric acid facilities. Figure 3 shows a pilot plant fitting in two 40-foot shipping containers that successfully proved the viability of this technology.[53] The pilot plant is designed in accordance with US-NRC 10 CFR Part 40 and is operated such that no more than 70 kg source material are extracted each year.

Given the relatively small footprint of such a plant, estimating the uranium extraction capability is worthwhile. Equation 4 provides a simple approach that is dependent on the given (0.41 l/s or 0.66 gpm) phosphoric acid volume flow.

$$\dot{V}_{WPA} \times \varphi_U \times D_U \times t = m_U \tag{4}$$

**Table 3.** Amount of material required to extract a significant quantity of uranium (IAEA).

| Material | | Use | Quantity [g/g $U_3O_8$] | Material required to extract a significant quantity of uranium [MT] |
|---|---|---|---|---|
| Sodium chlorate | $NaClO_3$ | Liquor oxidation (1st and 2nd cycle) | 1.80 | 21.22 |
| Ammonia | $NH_3$ | Stripping | 0.90 | 10.61 |
| Carbon dioxide | $CO_2$ | Stripping | 0.80 | 9.43 |
| Iron metal | Fe | Stripping | 0.50 | 5.90 |
| Di-(2-ethylhexyl) phosphoric acid | DEPA | Organic Extraction | <0.01 | <0.12 |
| Tri-n-octylphosphine | TOPO | Organic Extraction | <0.01 | <0.12 |


**Figure 3.** Urtek LLC uranium extraction pilot plant (Urtek LLC).

$\dot{V}_{WPA}$ = Phosphoric acid volume flow [l/s]
$\varphi_U$ = Uranium content of the phosphoric acid [g/l]
$D_U$ = Fraction of the uranium that is extracted
$t$ = Extraction time [s]
$m_U$ = Mass of the extracted uranium [g]

Assuming nearly continuous operation (with an availability factor of 0.90) the amount of uranium that could be extracted from phosphoric acid with relatively high uranium content (0.165 g/l) like Florida[54] and a recovery rate of 0.95 amounts to approximately 1,825 kg/year. Glaser[55] estimated that 280 kg natural uranium are required to produce 1 kg weapon grade HEU (90% uranium-235). A review of Iraq's nuclear weapons program revealed a design that would require about 16 kg of 90% enriched uranium. This would require 4,480 kg of natural uranium feed using Glaser's calculations.

**Table 4.** Wet phosphoric acid volume flow required at different locations to extract a significant quantity of uranium in a year.

| Location | $\varphi_U$ [g/l] | $\dot{V}_{H_3PO_4}$ [l/s] |
|---|---|---|
| United States, FL | 0.165 | 2.25 |
| Israel | 0.140 | 2.65 |
| Morocco | 0.119 | 3.12 |
| Iran | 0.083 | 4.47 |
| Jordan | 0.071 | 5.22 |
| Taiwan | 0.067 | 5.53 |
| Syria | 0.060 | 6.18 |
| Egypt | 0.040 | 9.27 |
| Tunisia | 0.037 | 10.02 |

The IAEA defines a significant quantity to be 25 kg HEU or 10 MT natural uranium.[56] Table 4 provides a brief overview of the required annual phosphoric acid flow that would be sufficient to extract a significant quantity of natural uranium with phosphoric acid used at different locations (again with $D_U = 0.95$ and 0.90 plant availability). Locations were chosen based on open source data and provide a brief overview of the different uranium concentrations at different deposits.[57]

Commercial WPA plants at which uranium was extracted had much higher throughputs than the values provided in Table 4. The IMC plant in New Wales, Florida, for instance operated with a feed ($\dot{V}_{WPA}$) ranging from 51–83 l/s producing some 245–269 MT uranium or 24–26 significant quantities per year.[58]

## Known unreported uranium extraction from domestic phosphate rocks

Uranium mining produces more uranium than phosphate processing plants; diverting material during traditional and in-situ leach uranium mining operations without raising attention of IAEA safeguards, is therefore easier. However, since phosphoric acid can be diverted to a side-stream, stripped of uranium, and returned to the fertilizer stream there may be fewer indicators of uranium extraction. The extraction route may thus be attractive for clandestine uranium accumulation if only phosphate rocks are available and primary uranium ores are not. In addition, even reported uranium byproduct extraction is often not considered a uranium mining operation by national regulations. Uranium extraction from unconventional resources should be reported to IAEA under its comprehensive safeguards agreement (INFCIRC/153) and additional protocol (INFCIRC/540) but has often been ignored or overlooked in practice.

Uranium from domestic phosphate rock sources contributed to nuclear programs in Israel[59] and the United States.[60] In 1949 Science Corps C, a special unit of the Israel Defense Forces started a two-year geological survey searching for uranium in the Negev desert. Uranium was found in phosphate rocks and Science Corps C eventually perfected the extraction process by 1953.[61] It is believed that Israel is still extracting some 10 MT[62] (1 Significant Quantity) or more uranium during domestic phosphate rock processing annually.[63]

Another example is the Al Qaim plant in Iraq were some 109 MT or nearly 11 Significant Quantities of uranium were extracted without reporting this to IAEA[64] before the facility was destroyed during the First Gulf War. The phosphate rock deposits in western Iraq contain some 40–80 ppm uranium.[65] Phosphate rocks were mined in Akashat and transported 150 km to the Al Qaim processing facility by train. The Al Qaim facility started operation in 1984 and played an important role for the country's fertilizer supply.[66] A facility to extract uranium from WPA was erected within two years from 1982 to 1984. It was designed to extract 103 MT uranium/year if operating 317 days/year, processing some 42 l WPA/s with 0.075 g uranium/l and a recovery rate of 0.93. As part of later inspections Iraq declared that the plant met less than 20% of its design capacity during its six years (1984–90) of operation. The poor plant performance was due to lower than anticipated uranium concentrations (approximately 60% of the design value), a drastically reduced flow rate (approximately 50% of the design value), a reduced recovery rate (approximately 0.78) and reduced overall plant availability (214 days/year on average). Though the plant did not meet the design specifications its activity was initially not reported to IAEA safeguards.[67]

## Known unreported uranium extraction from imported phosphate rocks

In addition to uranium extraction from domestic phosphate rocks, several countries import phosphate rocks for phosphate fertilizer production and extracted accompanied uranium from these imported resources. Belgium for instance reported the production of some 40 MT uranium annually at the Prayon Plant in Engis (near Liège) from Moroccan (Khouribga) phosphate rock from 1980 to 1998. Interest remains in uranium from phosphate rock rich regions as indicated by contracts between Areva (France) and OCP (Morocco).[68] For countries without considerable phosphate rock and uranium resources, such as India and Pakistan,[69] for whom buying uranium on the international markets is a struggle[70]; uranium from phosphate rocks may be of particular interest. As further evidence, Iran reportedly attempted to circumvent sanctions on the direct import of uranium ore by purchasing ores, including phosphate rocks, with a relatively high content of accompanying uranium.[71]

Phosphate rocks may be imported from multiple sources and be blended at a single facility. Material flows are, for instance, available for a plant in the Philippines that imports phosphate rocks from different sources and blends them prior to processing (without uranium extraction).[72] Blending makes it challenging to understand whether small or medium amounts of uranium were extracted given uranium concentrations in the phosphate rocks and final fertilizer products.

The Republic of Korea (ROK) considered developing nuclear weapons in the late 1960s due to worries about U.S. alliance guarantees against threats from the Democratic People's Republic of Korea (DPRK). ROK first decided to pursue plutonium production using a reprocessing facility, a research reactor and a heavy water reactor. Due to controls on dual-use technology because of India's 1974 nuclear test,

ROK's efforts to gain weapons grade plutonium were uncovered. Though never of significance for a weapons program, ROK's nuclear activities continued in the early 1980s by selectively importing phosphate rock with high uranium content, so that uranium could be extracted and used for clandestine enrichment experiments.[73]

## Conclusion

Acquiring natural uranium is the first step to producing nuclear explosives. In addition to conventional sources, phosphate rocks are a promising source of unconventional uranium. Due to the global abundance of phosphate rocks as well as its large trade volumes for fertilizer production, relevant for global food security, it is unlikely that IAEA or any other organization will have the capacity to monitor uranium extraction from domestic or imported phosphate rocks. Additionally, this could be considered a poor use of IAEA resources. Knowledge that significant amounts of uranium may be transferred to states that have few uranium resources but possible nuclear weapon programs is useful though. Guidelines for the declaration of mined uranium that include unconventional uranium from extraction activities are in place. We urge IAEA as well as all its Member States to make use of them, close potential loopholes and thus enable resource conversation and the production of cleaner fertilizer globally.

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