Human Resource Development for Uranium Production Cycle

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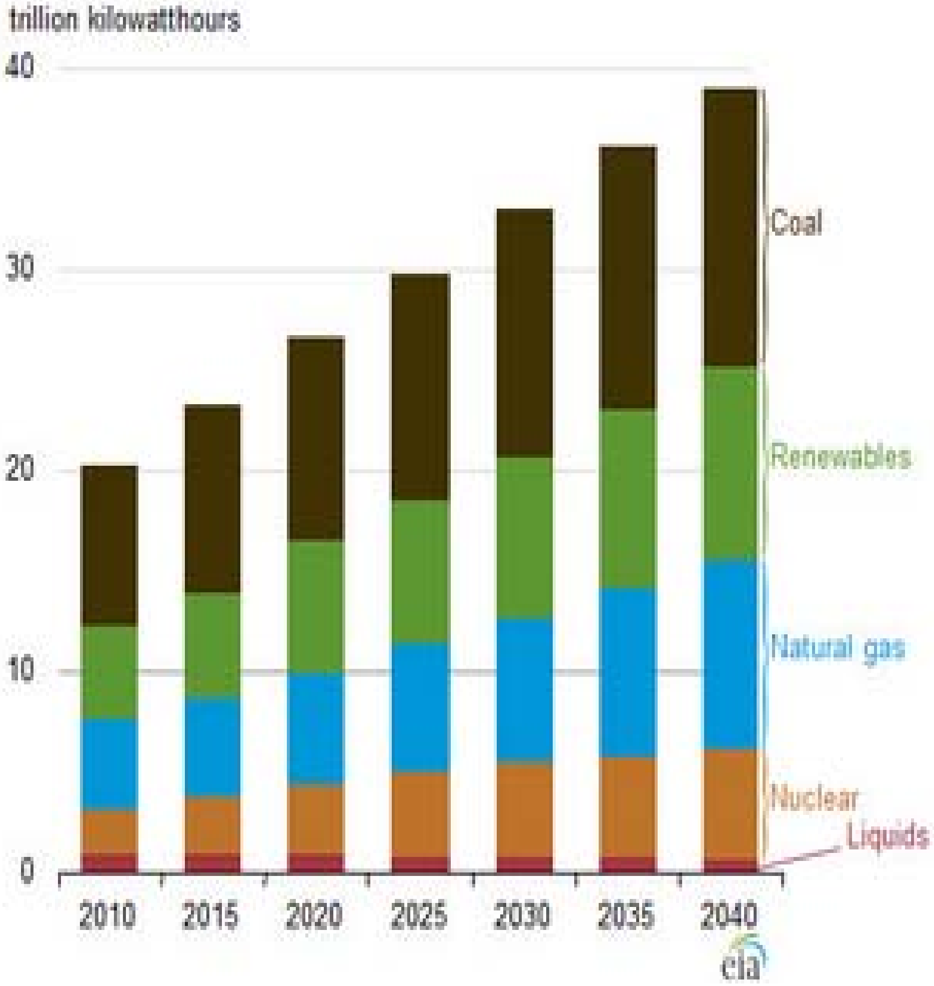
Projected World Net Electricity Generation till 2040 : (A) By Fuel & (B) from Nuclear Power

(Ref International Energy Outlook July , 2013)

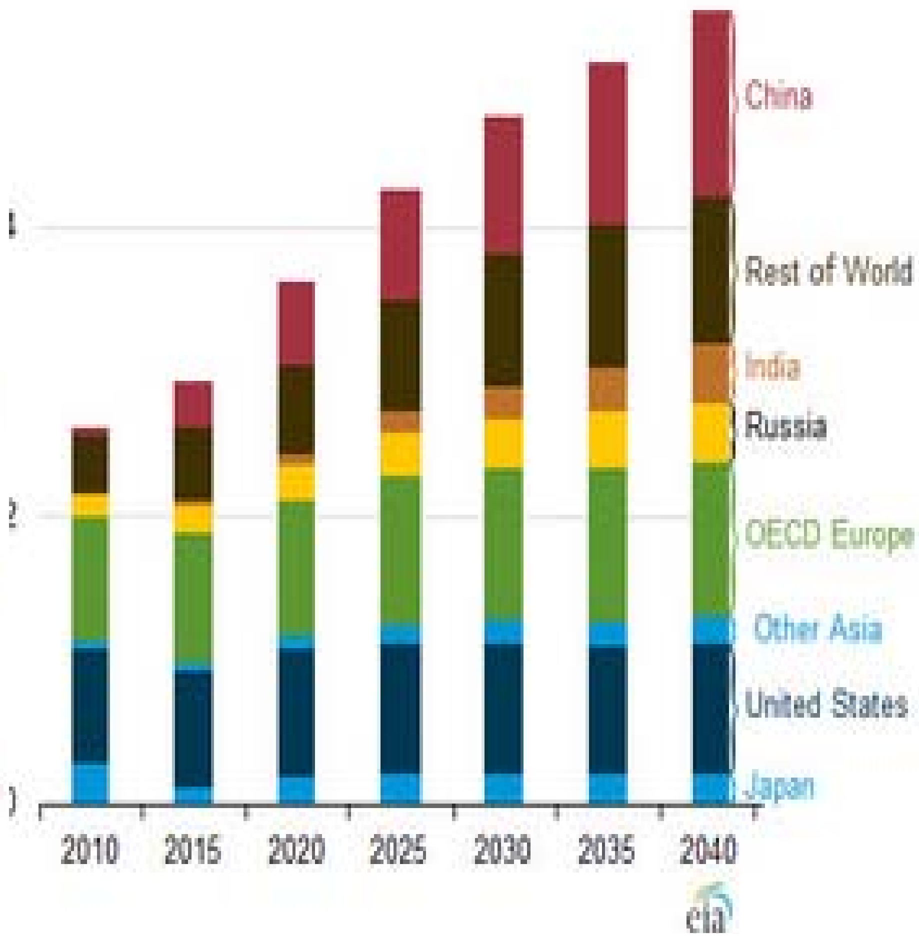
(A)

Contribution from nuclear , natural gas & renewable energy sources will grow but coal will still continue to have the major share. Generation from nuclear power is expected to grow by 2.5 % per year till 2040



(B)

Electricity generation from nuclear power is likely to increase from 2,620 billion kWh in 2010 to 5,492 billion kWh in 2040. Major growth of nuclear power foreseen in China & India mainly

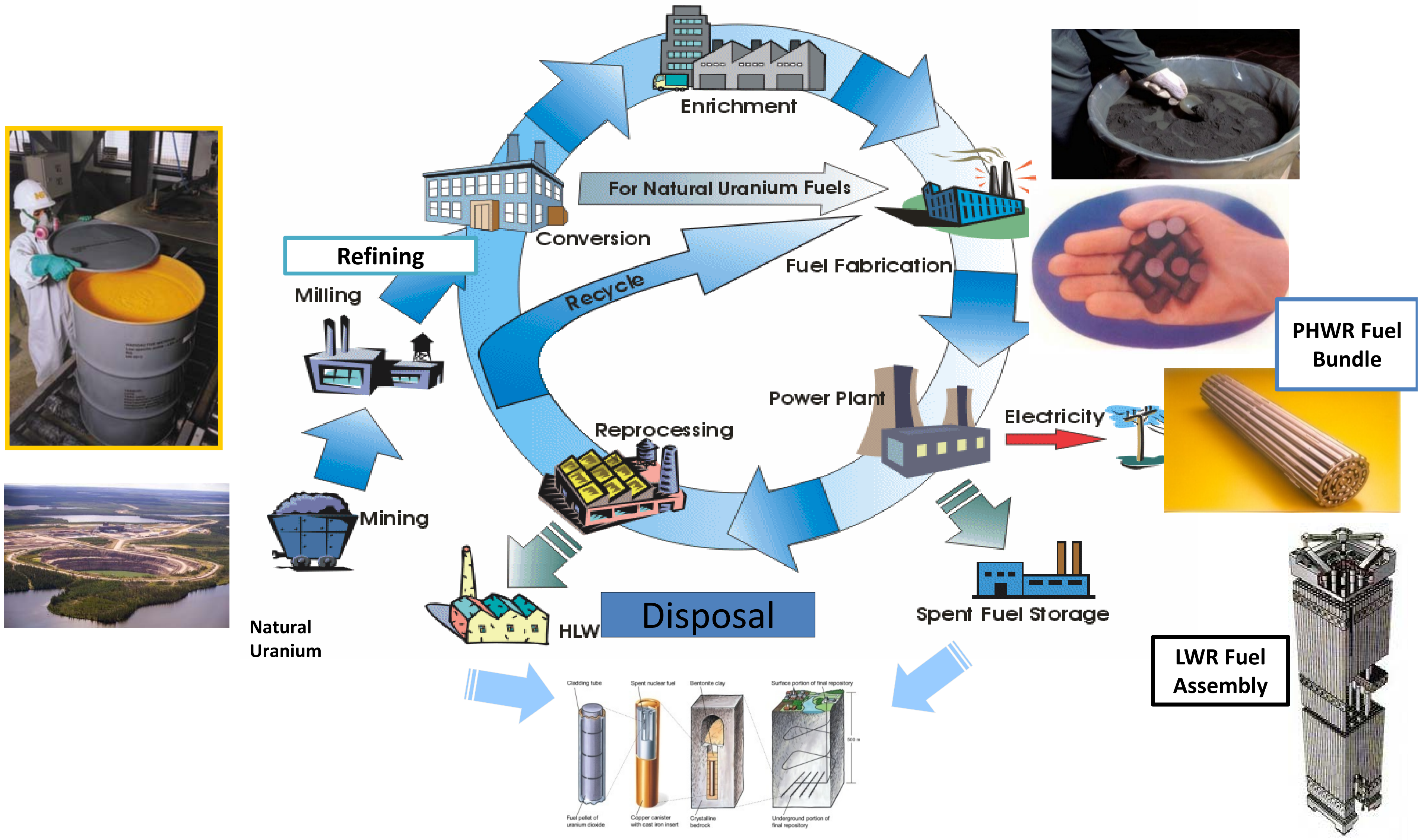


Uranium Fuel Cycle

Natural Uranium is the Basic Raw Material for Nuclear Fuels

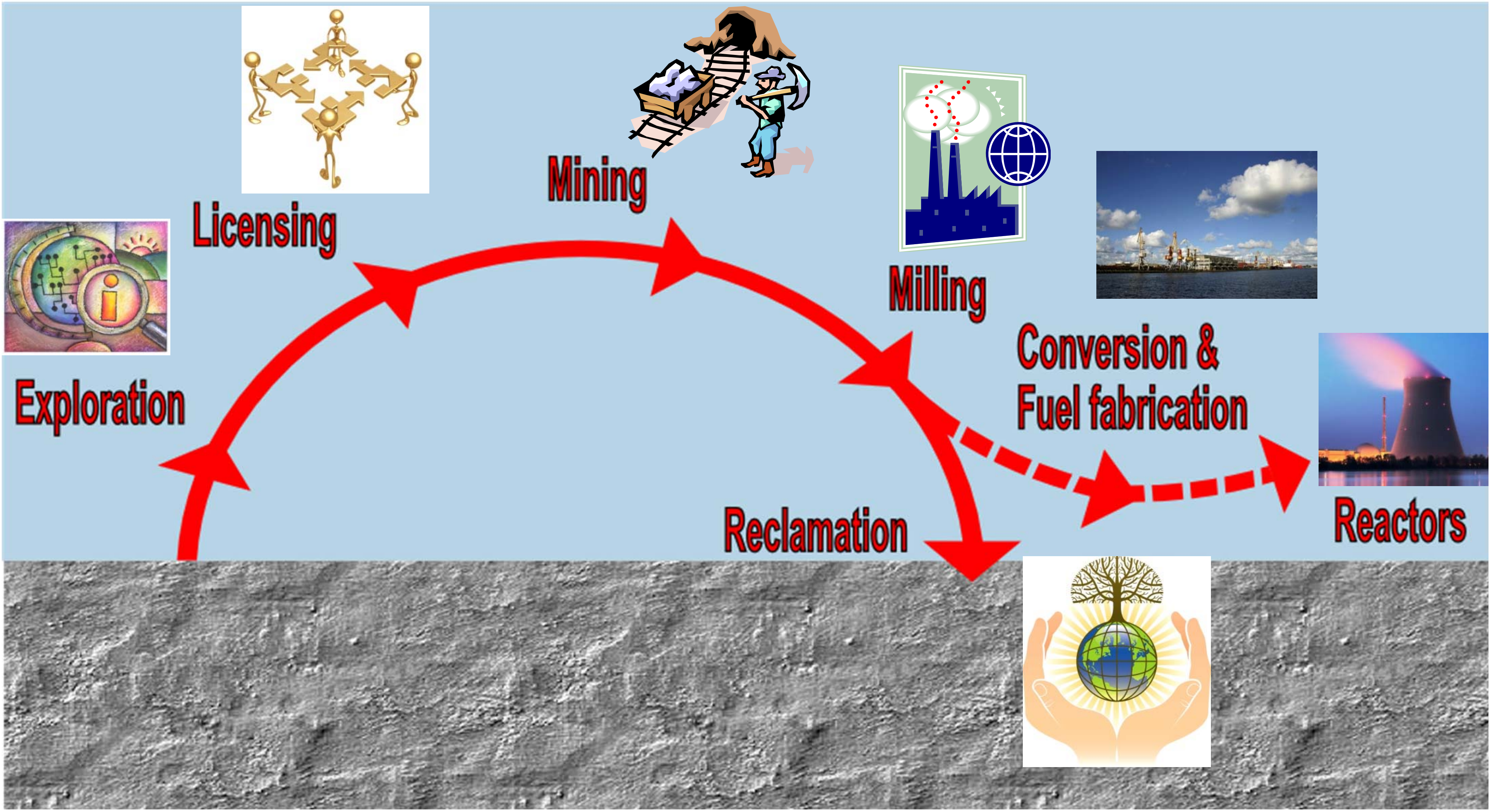
PHWR Fuel Pin Bundle : Zr alloy clad natural uranium(0.7 % U^{235}) oxide fuel pellets

LWR Fuel Rod Assembly : Zr alloy clad enriched uranium (1.5-5 % U^{235}) oxide pellets



Uranium Production Cycle

Radiological Safety (radon and radium management) and Mine & Mill Remediation and Reclamation are the Major Challenges

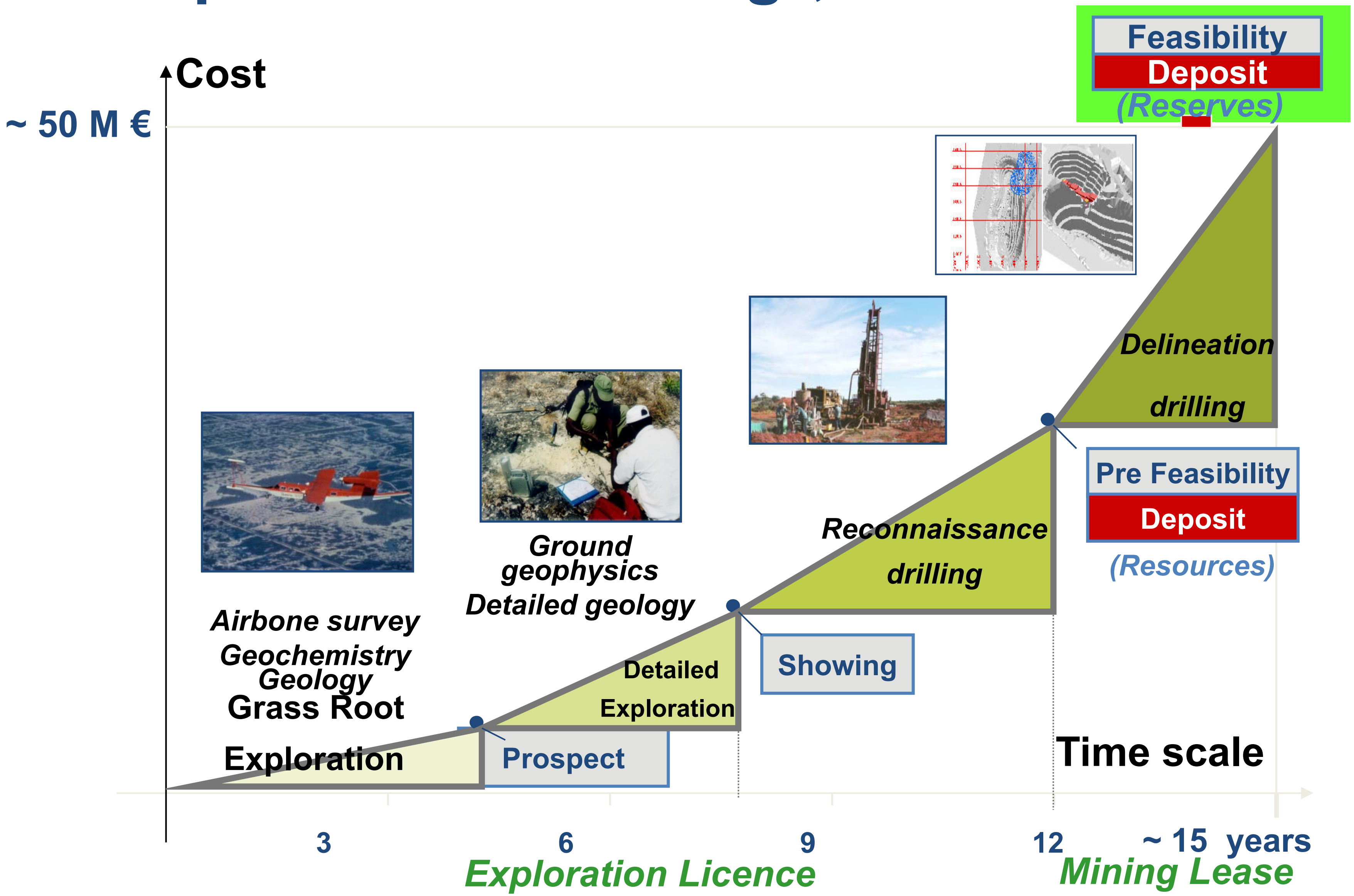


Common Techniques for Uranium Exploration

(uranium exploration and development are high cost, high risk activities)

- **Geological Mapping : Uranium deposits are not distributed at random in the earth's crust but are geologically controlled and occur only in certain geological environment. Good geological maps are tedious and time consuming to prepare and show source area and depositional areas. Uranium is concentrated in conglomerates, sandstones , phosphatic limestone, coal & black shale and in the vicinity of unconformities.**
- **Remote sensing : Photogeological interpretation of aerial photographs, satellite images , airborne radar images, and other multispectral scanning images to obtain additional geological and uranium favourability information on a regional scale**
- **Radiometry : Air borne (helicopter or airplane) and car borne total count and gamma ray spectrometry surveys, based on measuring Bi 214 and Tl 208, gamma emitting daughter products of 238 U and 232 Th series, are used in uranium exploration , permitting the coverage of large areas rapidly and conveniently at the reconnaissance and follow-up phases. However, the gamma rays being measured have a short depth penetration, in the order of 50 cm in rock, implying that buried mineralization may not be detected.**
- **Geochemical Methods Collection and analysis of samples of materials from the surface environment, water, lake or stream, sediment, soil, rock or gas (radon in particular) for one or a number of elements.**
- **Geophysical Methods Air borne and ground magnetic and electro magnetic survey to locate sulphide minerals, graphite and other conducting structures associated with the uranium mineralization particularly in granitic environments. They provide information about both concealed and exposed bedrock , have the ability to penetrate the surface and can be a direct pointer to ores that are magnetic and/or conductive.**

From Exploration to Mining*; Time and cost



*Before licencing

(Mine and Mill licencing and building : 5 to 10 y needed – 200->500 M €)

Uranium Mining Techniques (Total Production ~ 59,000 tons in 2013)

(U and its decay products Ra 226 & radon 222 (gas)are radioactive & health hazardous)

Radiological Safety in Mines and Tailing Ponds and Mine Remediation & Reclamation are unique for Uranium Mining

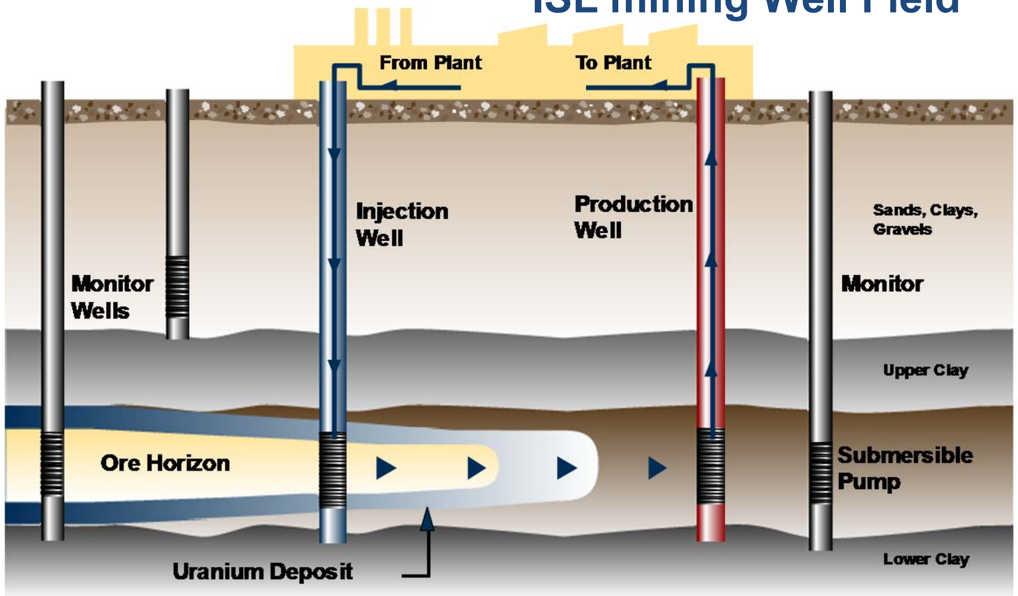
Open Pit Mining (~ 20%)

In Situ Leach (ISL) Mining (~ 45%)

By-product (~ 7%)

ISL mining Well Field

Underground Mining (~ 28%)



The Four Major Steps in Uranium Milling - Production of Uranium Ore Concentrate (popularly known as yellow cake) from Uranium Ore [Ref : IAEA Report Series 359 , 1993]

1. **Crushing & Grinding of Ore and Preparation of Slurry**

2. **Leaching or Dissolution in Acid (sulphuric acid) or Alkali (sodium carbonate or bicarbonate) with or without oxidizing agent**

$UO_3 + 2H^+$ ====> $UO_2^{2+} + H_2O$

sulphuric acid leaching : $UO_2^{2+} + 3SO_4^{2-}$ ====> $UO_2(SO_4)_3^{4-}$

sodium carbonate/bicarbonate leaching : uranyl tricarbonate ion: $UO_2(CO_3)_3^{4-}$

3. **Purification by Solvent Extraction (SX) or Ion Exchange (IX)** [40 % & 90 % of mill capital & operation costs respectively]

In SX, tertiary amines are used in a kerosene diluent as Solvent and in IX a resin/polymer

$2R_3N + H_2SO_4$ ====> $(R_3NH)_2SO_4$2 $(R_3NH)_2SO_4 + UO_2(SO_4)_3^{4-}$ ====> $(R_3NH)_4UO_2(SO_4)_3 + 2SO_4^{2-}$

"R" is an alkyl (hydrocarbon) grouping, with single covalent bond.

The loaded solvents is treated with sulfuric acid to remove cation impurities at pH 1.5, then with gaseous ammonia to remove anions impurities and finally stripped in a countercurrent process using ammonium sulfate solution:

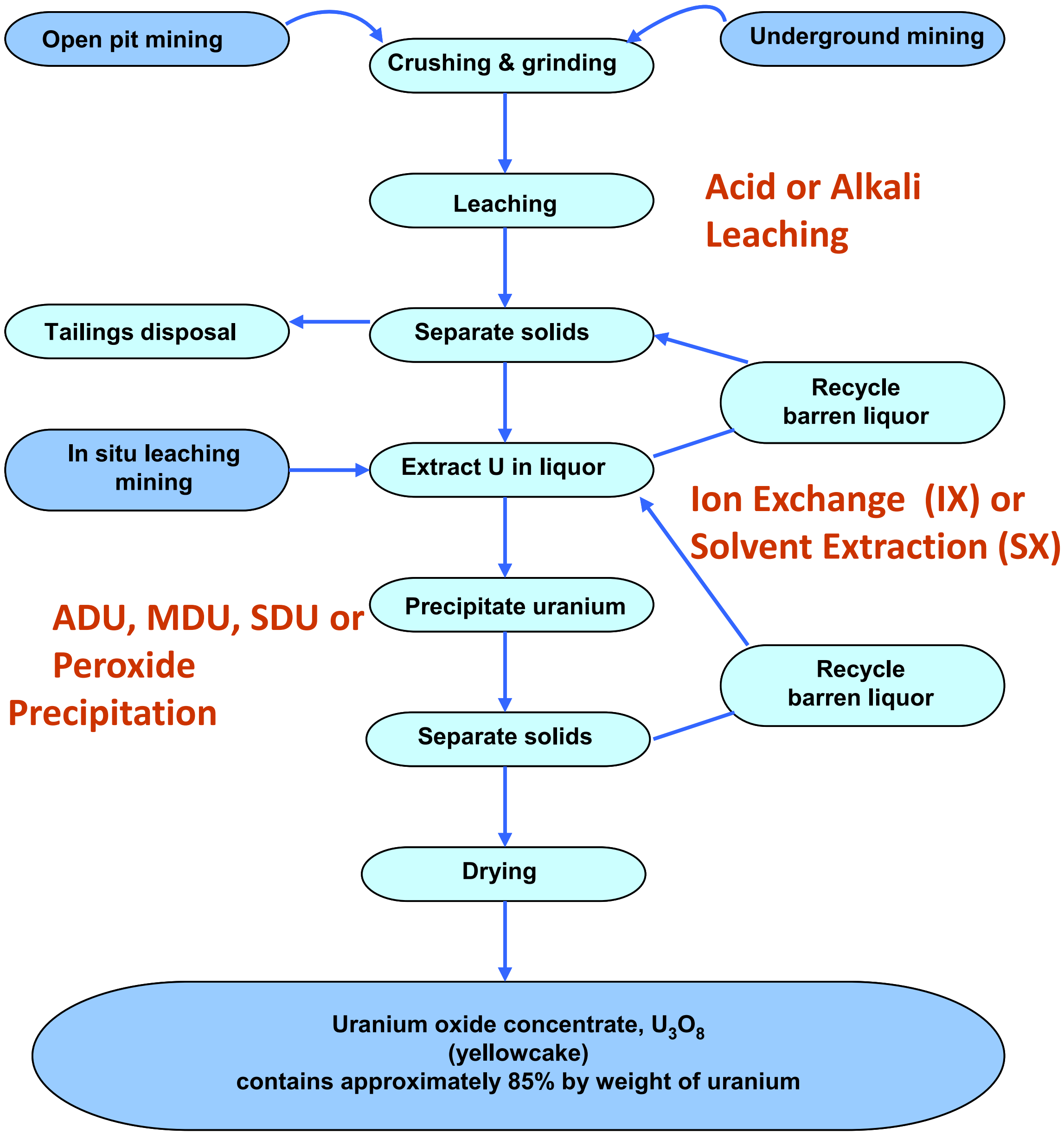
$(R_3NH)_4UO_2(SO_4)_3 + 2(NH_4)_2SO_4$ ====> $4R_3N + (NH_4)_4UO_2(SO_4)_3 + 2H_2SO_4$

4. **Precipitation as ADU, MDU, NDU or Peroxide followed by Drying and Calcination.**

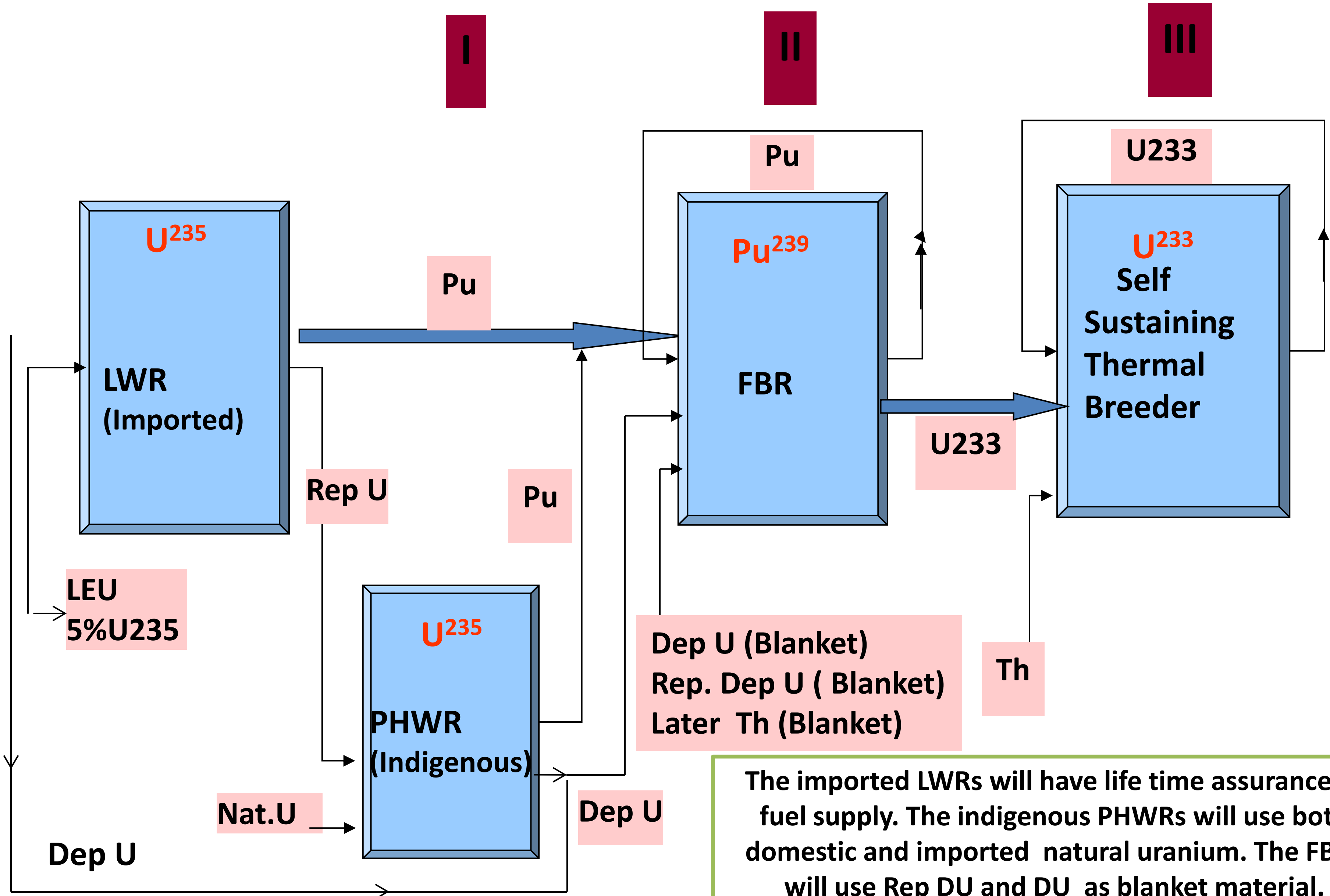
Precipitation of Ammonium Diuranate (ADU) by adding gaseous ammonia to neutralise the solution , though in some plants caustic soda and magnesia are used to precipitate Sodium Diuranate (NDU) and Magnesium Di Uranate (MDU) respectively

- 2NH3 + $2UO_2(SO_4)_3^{4-}$ ====> $(NH_4)_2U_2O_7 + 4SO_4^{2-}$

Outline of Process Flowsheet in Uranium Milling Plant & Statistics of World Uranium Production in 2013 (Total : ~ 59,000 tons) ISL Mining Accounting for ~ 50 % in 2013



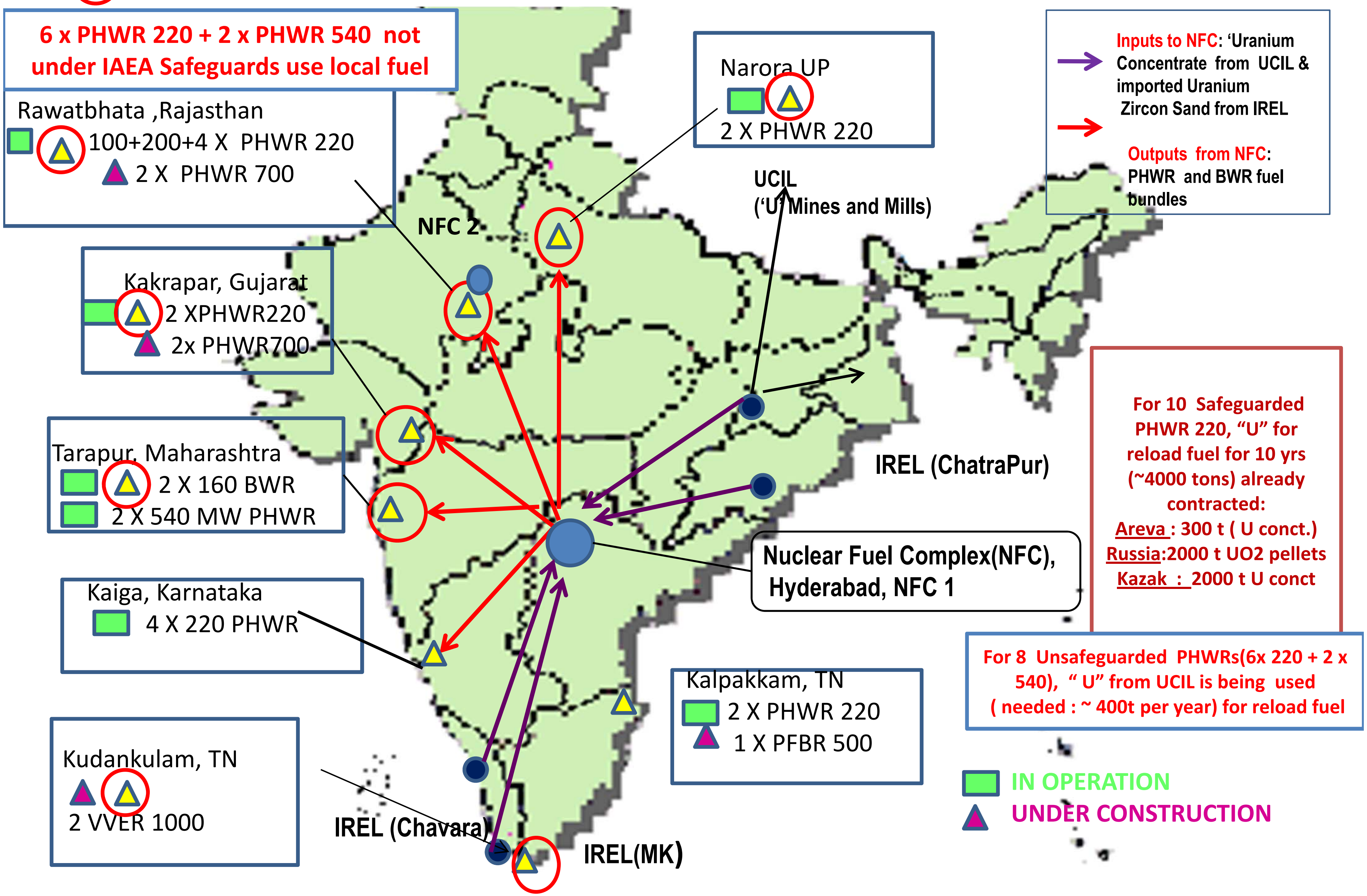
Proposed Nuclear Fuel Cycle in India Linking Imported LWRs (VVER 1000 , EPR 1650 , AP1000 & ESBWR 1350), Indigenous PHWRs , FBRs and Thermal Breeders



The imported LWRs will have life time assurance of fuel supply. The indigenous PHWRs will use both domestic and imported natural uranium. The FBRs will use Rep DU and DU as blanket material.

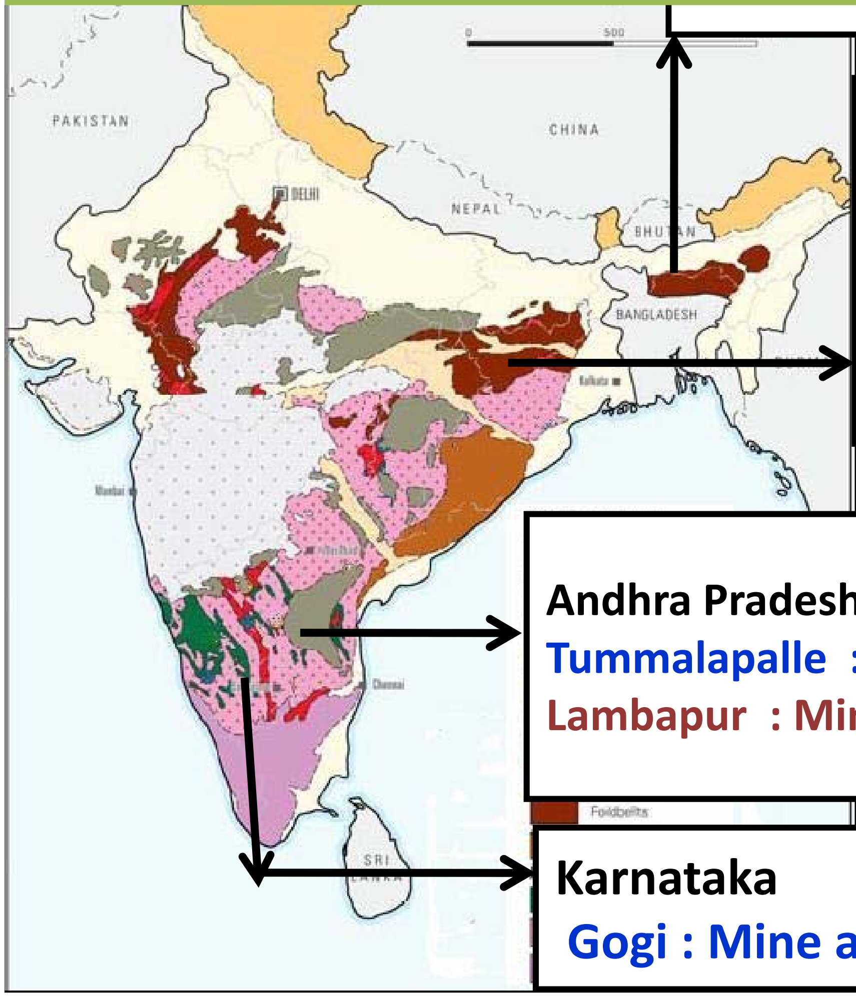
Nuclear Fuel Fabrication in India for Operating PHWRs(CANDU) and 2 BWRs

10x PHWR 220 + 2x BWR 160 + 2 x VVER 1000 under IAEA Safeguards use imported 'U' Fuel



Uranium Mines & Mills in INDIA

(Ref : R Gupta , UCIL Paper)



Jharkhand:

Operating Mines : Jaduguda, Bhatin, Narwapahar, Turamdih, Bagjata, Banduhurang;

Mills : Jaduguda and Turamdih;

Mine under construction : Mohuldih;

Andhra Pradesh

Tummalapalle : Mine and Mill in operation since 2012,

Lambapur : Mine and Mill planned :

Karnataka

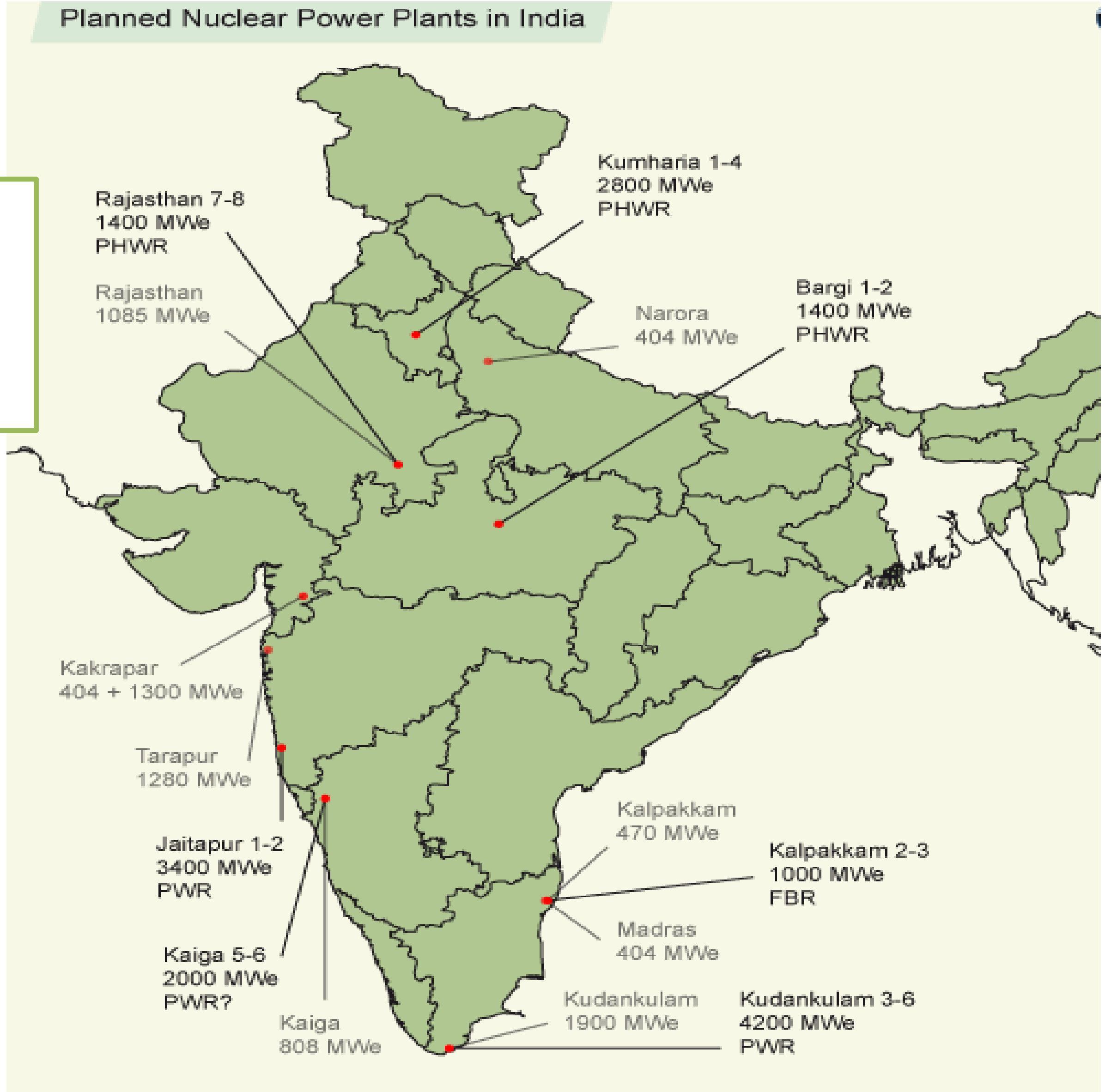
Gogi : Mine and Mill under planning

Location of Planned Nuclear Energy Parks in India -

Indigenous PHWR 700 MWe & FBR 500 MWe units and

Imported LWR units from Areva , France (6x EPR 1650), Rosatom , Russia (8 x VVER 1000), Westinghouse- Toshiba , USA (6 x AP 1000) & General Electric- Hitachi , USA (6 x ESBWR 1350)

Target :
14,600 MWe by 2020
~ 45,000 MWe by 2032



Annual Recruitment at BARC Training Schools and under DAE – Graduate Fellowship Scheme Managed by Homi Bhabha National Institute (HBNI), a Deemed University at Mumbai

1. One-Year Orientation Course for Engineering Graduates & Science Post-Graduates [OCES] followed by posting of Training School Officers (TSO) in different units of Department of Atomic Energy (DAE)

Recruitment in August at BARC Training Schools situated at: BARC, Mumbai; IGCAR,Kalpakkam; NFC, Hyderabad; RRCAT, Indore; AMD, Hyderabad. (some 300 graduates & postgraduates recruited every year)

2. Two-Year DAE Graduate Fellowship Scheme for Engineering Graduates and Physics Post-Graduates [DGFS]

Recruitment in July for joining M.Tech. in select specialisations at IITs – Bombay, Delhi, Guwahati, Kanpur, Kharagpur, Madras, Roorkee and BHU-Varanasi; NIT - Rourkela; Institute of Chemical Technology (ICT) – Mumbai.

3 . Both OCES TSOs & DGFS Fellows get opportunities for pursuing Ph.D. through HBNI University

Annual Recruitment of Graduate Engineers & Post Graduates in Science Stream in BARC Training Schools under Homi Bhabha National Institute (HBNI) in Mumbai

Training School	Disciplines (refer Table-1)	Orientation of Training	Probable Placement after Training*#
BARC, Mumbai (Since 1957)	21 to 27, 29 & 41 to 44	• Engineering Design, development, operation and maintenance of Nuclear Reactors • Research in frontier areas of Basic and Engineering Sciences	Mainly in **BARC**
IGCAR, Kalpakkam (Since 2006)	21, 22, 25, 27, 41 & 42	• R&D and Engineering related to Fast Breeder Reactors • Research in frontier areas of Basic and Engineering Sciences	Mainly in **IGCAR**
RRCAT, Indore (Since 2000)	24, 25 & 41	• R&D and Engineering related to lasers, accelerators, plasma physics, cryogenics and superconductivity	Mainly in **RRCAT**
NFC-HWB, Hyderabad (Since 2001)	21, 22, 24, 25 & 27	• Operation & Maintenance and Engineering related to Nuclear Fuel Facilities and production plants for production of Heavy Water to support the Nuclear Power Program	Mainly in **NFC or HWB**
AMD, Hyderabad (Since 2010)	45, 46	• Exploration Techniques for Uranium and other Atomic Minerals and related R&D activities	Mainly in **AMD**

Table 1 Disciplines : 21 Mechanical, 22 Chemical , 23 Metallurgical , 24 Electrical , 25 Electronics , 26 Computer Science, 27 Instrumentation , 29 Civil , 41 Physics, 42 Chemistry , 43 Bio Sciences , 44 Radiological Safety Engineering, 45, Geology, 46 Geophysics

Around 300 Trainees are recruited Annually : 150 in BARC, 50 in IGCAR, 35 in NFC-HWB, 35 in RRCAT & 30 in AMD

For Uranium Corporation of India Limited (UCIL) there is still no dedicated Training School

One Year Course For Engineering Graduates At BARC Training School , NFC , Hyderabad –

Post - Training Placement in Nuclear Fuel Complex (NFC),Heavy Water Plants & Nuclear Fuel Cycle Group.

[For Mechanical , Chemical, Electronics & Communication and Instrumentation Engineers]

Annual Intake 25-40 Engineering Graduates

MODULES FOR THE COURSE :

1. Nuclear Engineering Module (Common to all Trainees)

2. Core Engineering Module

3. Core Elective Model

Placement in DAE units after passing all tests under the above modules

4. Project Work at the Placement Unit

NUCLEAR ENGINEERING MODULE

1. Engineering Mathematics (30 hours)
2. Nuclear & Reactor Physics (35 hours)
3. Reactor Engineering & Radiation Shielding (30 hours)
4. Health Physics, Chemical Plant Safety & Environmental Engineering (30 hours)
5. Nuclear Power Plant Engineering - PHWR, LWR & FBR (30 hours)
6. Materials Science in Nuclear Engineering (25 hours)
7. Nuclear Fuel Cycle, Heavy Water Production Technology, Isotope Separation Technology & Reactor Coolant Water Chemistry (45 hours)

Proposed 2 years Post Graduate Course in Nuclear Engineering with Specialization in Nuclear Fuel Cycle

First Year : Theoretical Studies (2 semesters)

NUCLEAR ENGINEERING MODULE

Engineering Mathematics 40 h

Reactor Physics & Reactor Engineering 40 h

Nuclear Power Plant Engineering - PHWR, LWR & FBR 40 h

Safety, Security & Safeguards 40 h

Nuclear Fuel Cycle Module

- **Specialization in Uranium Production Cycle (40 h)**
- Uranium Geology
- Uranium Exploration
- Uranium Mining
- Uranium Milling & Refining
- Uranium Mine & Mill Remediation & Reclamation
- **Specialization in Uranium Fuels & Fuel Cycle (40 h)**
- Uranium Oxide Fuel Fabrication
- Fuel Performance & Post Irradiation Examination
- Spent Fuel Management
- Treatment & Disposal of High Active Waste

Second Year : Practical Training in Uranium Mine , Mill & Fuel Fabrication Plant Or Research & Development in Nuclear Fuel

Concluding Remarks & Suggestions

- HRD will be one of the major challenges in the expanding nuclear power program in countries like China and India

- China and India get uranium raw material from domestic mines and international market . In addition , China has overseas uranium property . India is also exploring the possibility of overseas Joint Venture and uranium properties. For uranium production cycle there is a need for trained geologist , mining engineers , chemical and mechanical engineers.

- There is a need for introducing specialization course on “uranium production cycle” at post graduate levels in government and private universities . Overseas Utilities and private firms in India engaged in nuclear power and fuel cycle activities may like to sponsor MTech students with assurance of employment after the successful completion of the course.

- The IAEA may consider to extend Technical Assistance to universities in HRD in nuclear power and fuel cycle in general and uranium production cycle in particular - IAEA workshops , with participation of international experts, on uranium geology , mining , milling and safety and best practices in uranium production cycle will be of great help .
- The IAEA – UPSAT could play an important role in HRD in uranium production cycle