Assessing uranium resources availability to 2060

Harikrishnan ‘Hari’ Tulsidas
Division of Nuclear Fuel Cycle & Waste Technology

IAEA
International Atomic Energy Agency

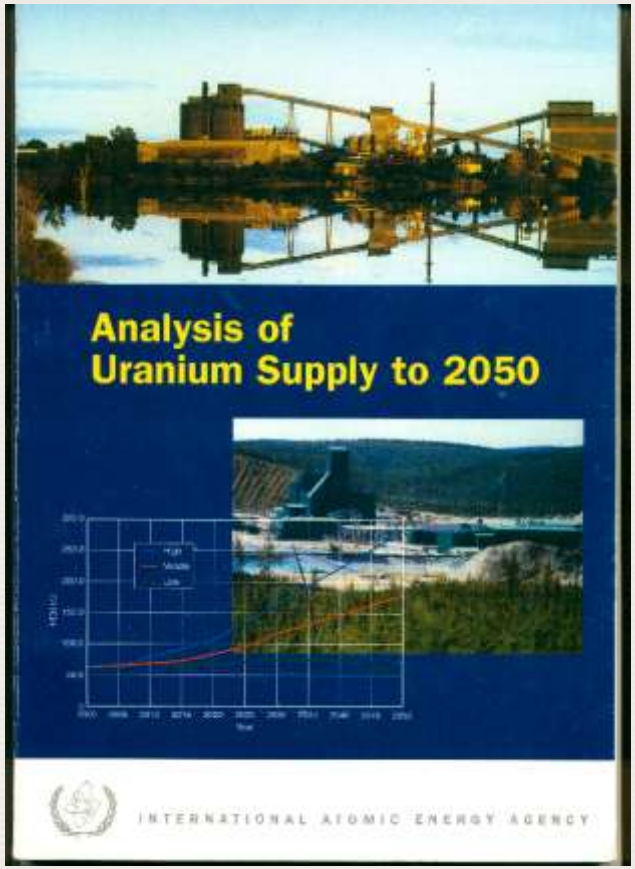
Contributors

- Christine Atkinson, USA
- Jean Rene Blaise, France
- Thomas Pool, USA
- Douglas Underhill, USA
- Robert Vance, NEA
- Kimberly Warthan, USA
- Harikrishnan Tulsidas, IAEA

IAEA

Outline

- Background
- Uranium Requirements
  - Reactor Requirements
  - Inventory Accumulation
- Uranium Supply
  - Secondary Supply
  - Primary mineral inventory
    - Resource classification
    - Uranium resources
    - Markets
    - Unconventional resources
  - Primary Production
- Supply – Demand Balance
- Conclusions



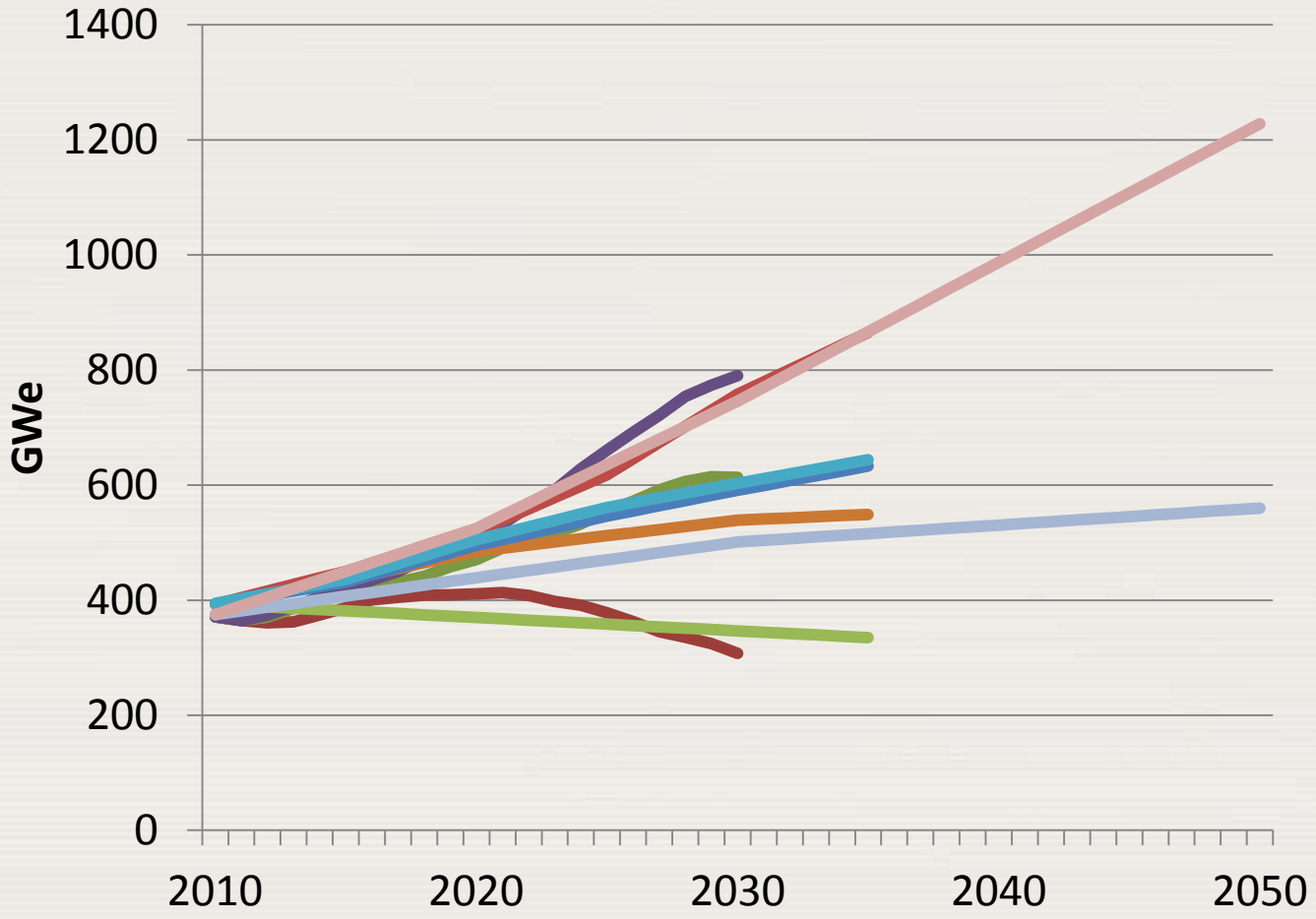
IAEA

Uranium requirements

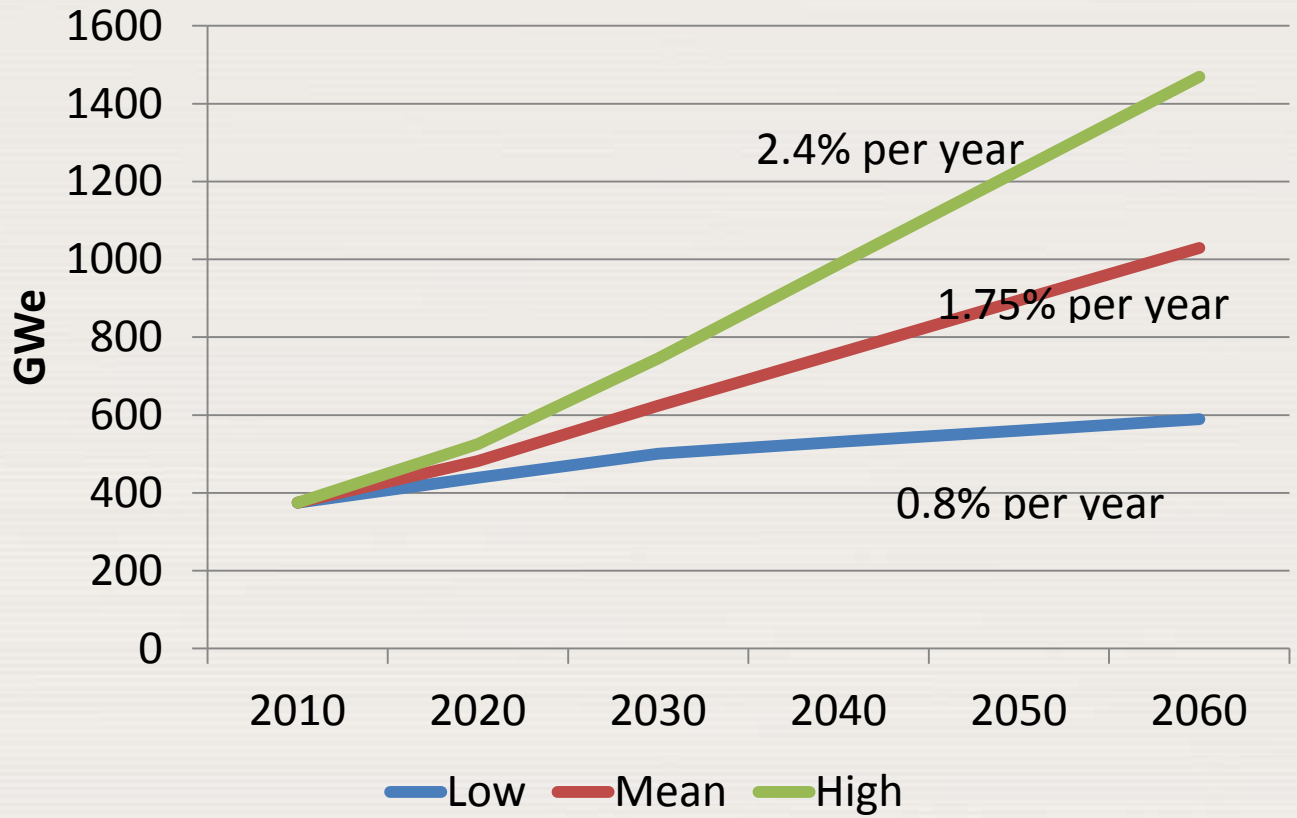
- Available Projections – Installed Capacity
  - World Nuclear Association – 2011
    - 2005 to 2030
  - International Energy Agency – 2011
    - 2010 to 2035
  - U. S. Energy Information Administration – 2011
    - 2008 to 2035
  - International Atomic Energy Agency – 2011
    - 2010 to 2050

IAEA

Installed nuclear capacity projections, 2011



Projected nuclear capacity



Installed Nuclear Generating Capacity – IAEA – 2011 (GWe)					
	2010	2020	2030	2050	2060
High	375	525	746	1228	1469
Mean	375	482	624	894	1029
Low	375	439	501	560	589

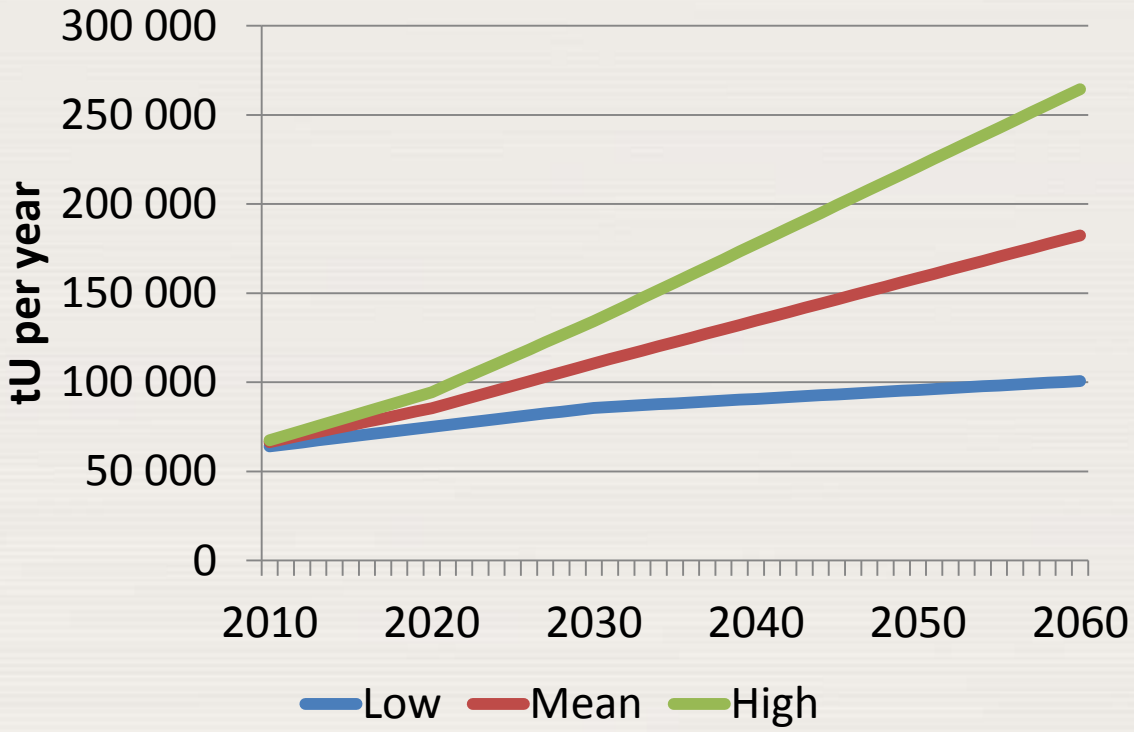
IAEA

Capacity to Uranium requirements

- Determine “Fuel Intensity”
  - Average of calculations from WNA “Global Nuclear Fuel Market” and NEA/EIA “Uranium 2009: Resources, Production and Demand”.
  - High Case = 180 tU per year per GWe
  - Mean Case = 177.3 tU per year per GWe
  - Low Case = 171 tU per year per Gwe
  - High & mean cases are higher due to more initial cores.

IAEA

Reactor requirements



Projected Long-Term Uranium Requirements (tU)							
	2010	2020	2030	2040	2050	2060	Total
High	67,500	94,500	134,280	177,660	221,040	264,420	8,100,360
Mean	66,488	85,459	110,635	134,571	158,506	182,442	6,260,084
Low	64,125	75,069	85,671	90,801	95,760	100,719	4,379,652

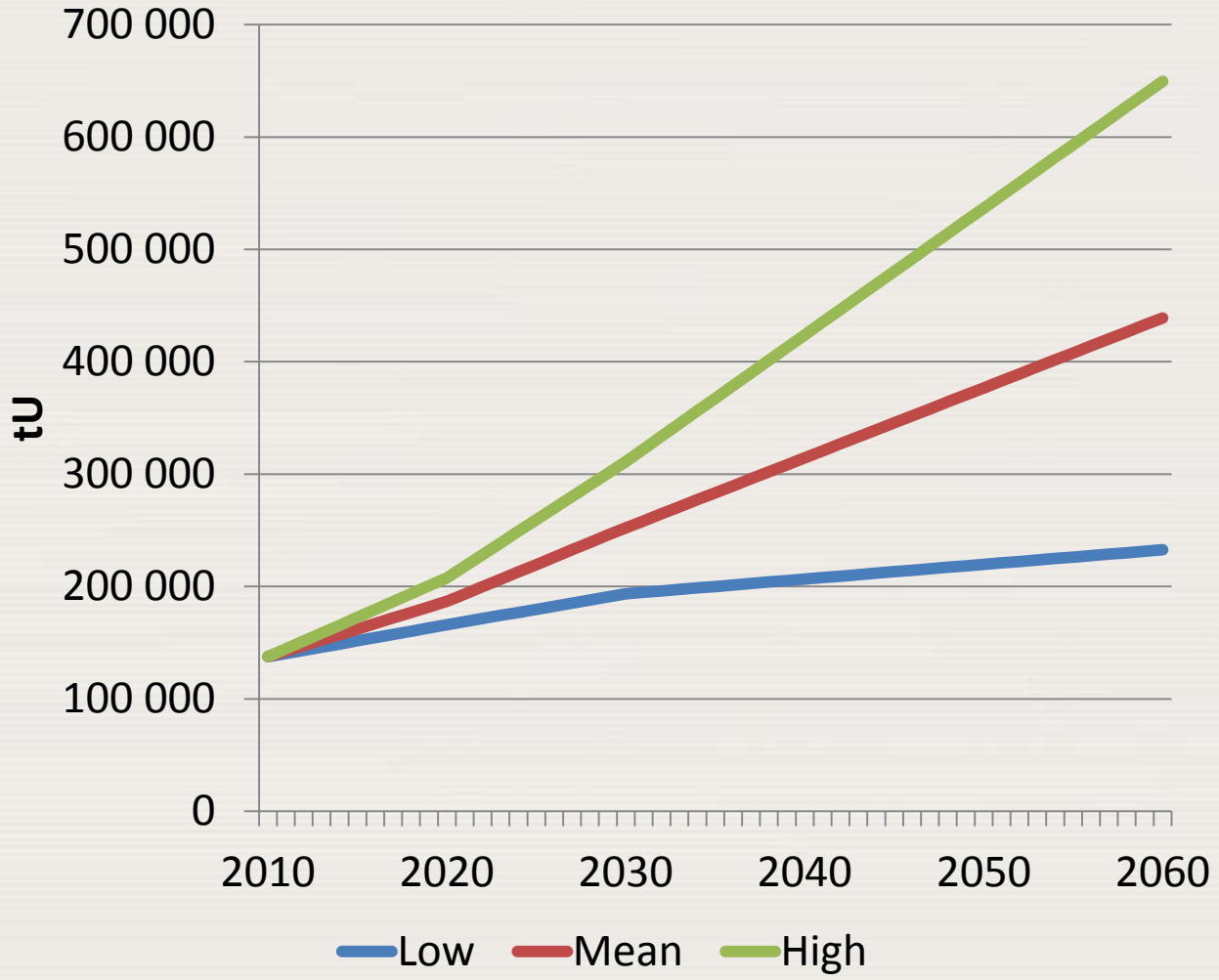
IAEA

Commercial Inventory Accumulation

- Utilities: 2.0 years forward requirements
- Producers: 0.5 years forward supply
- Brokers/Traders/Investors: 10% of annual requirements

IAEA

Commercial Inventories

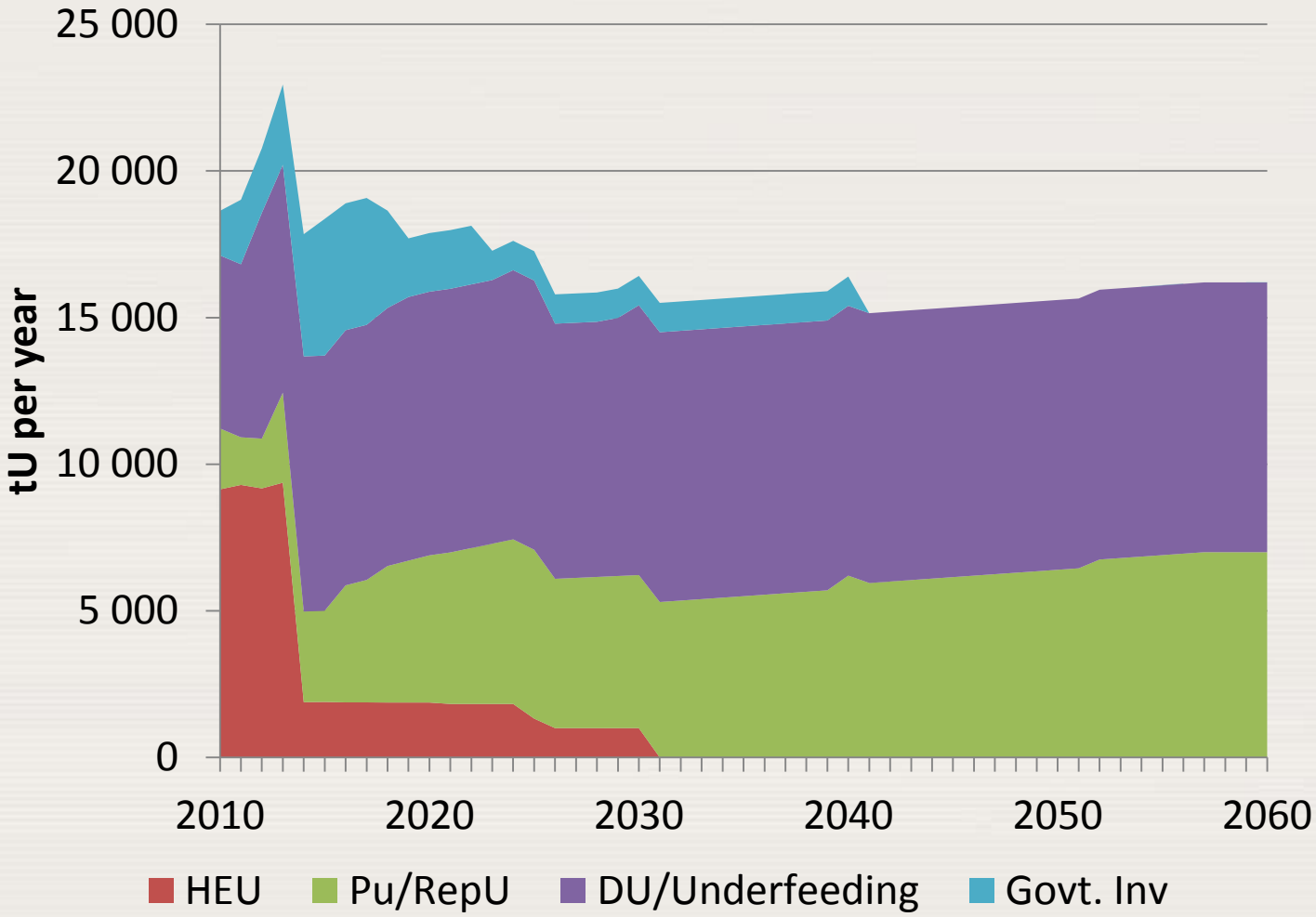


Secondary Supply

1. Highly enriched uranium (HEU)
2. Reprocessed uranium (RepU) from spent nuclear fuel
3. Plutonium for mixed oxide fuel (MOX)
4. Depleted uranium in the form of enrichment tails (DU) and underfeeding
5. Government holdings of natural (NU) and low enriched uranium (LEU)

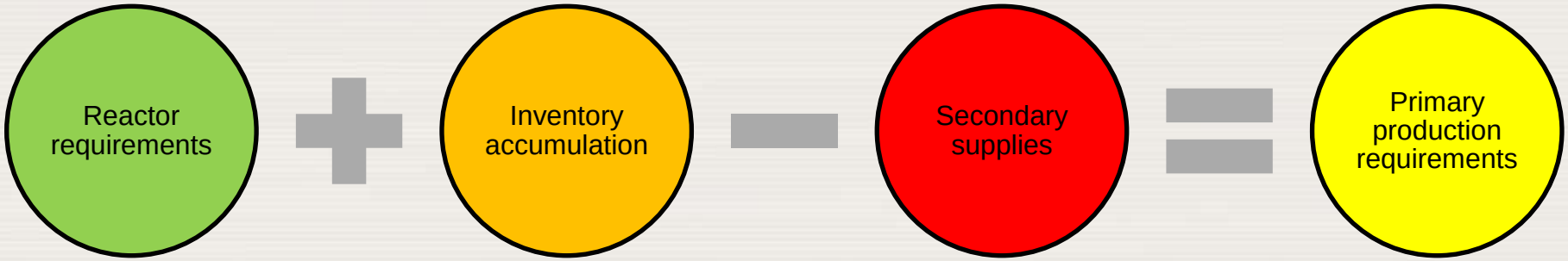
IAEA

Secondary supply



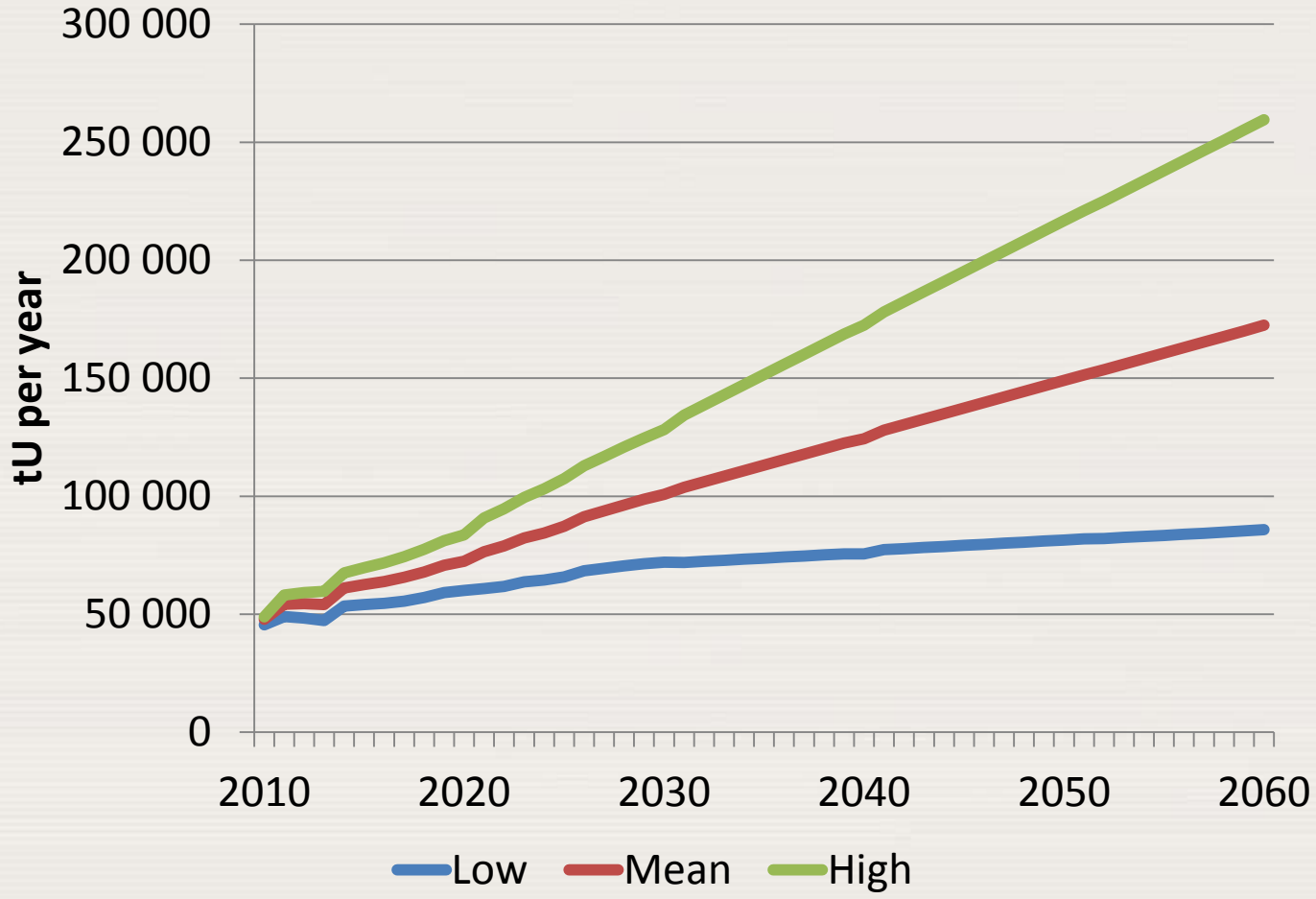
IAEA

Primary production requirements



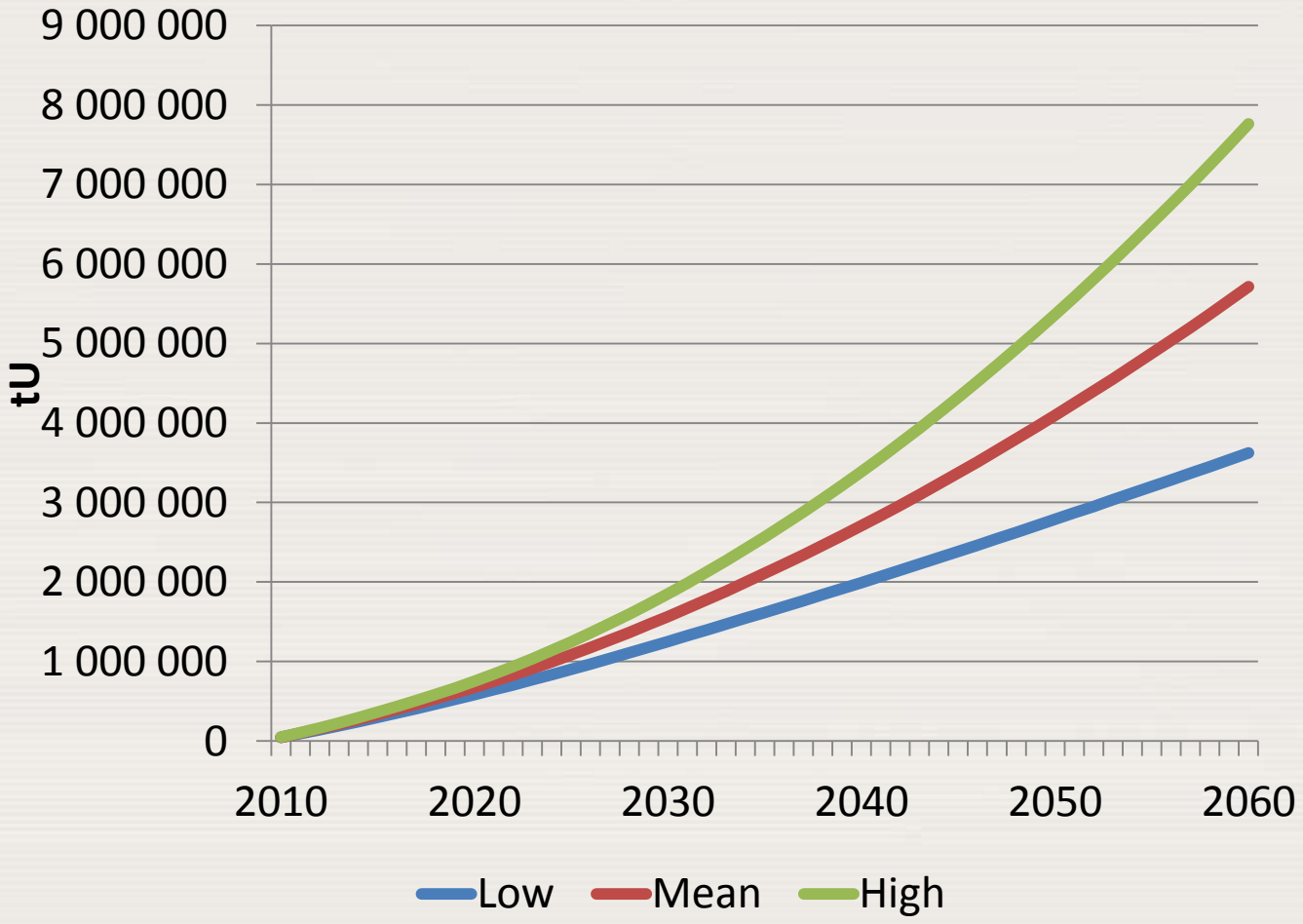
IAEA

Primary production requirements



IAEA

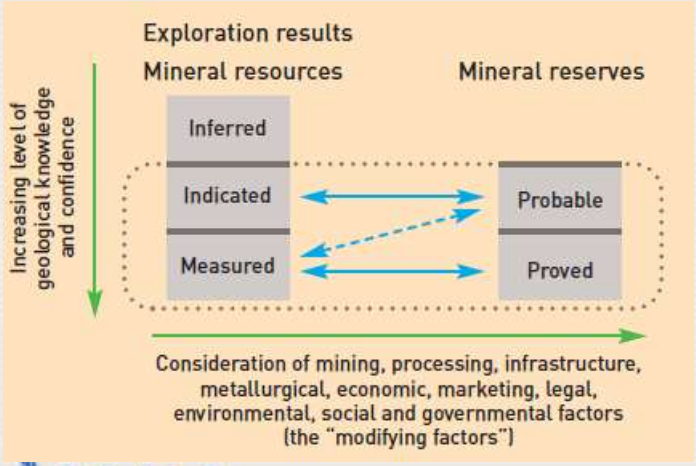
Cumulative production requirements



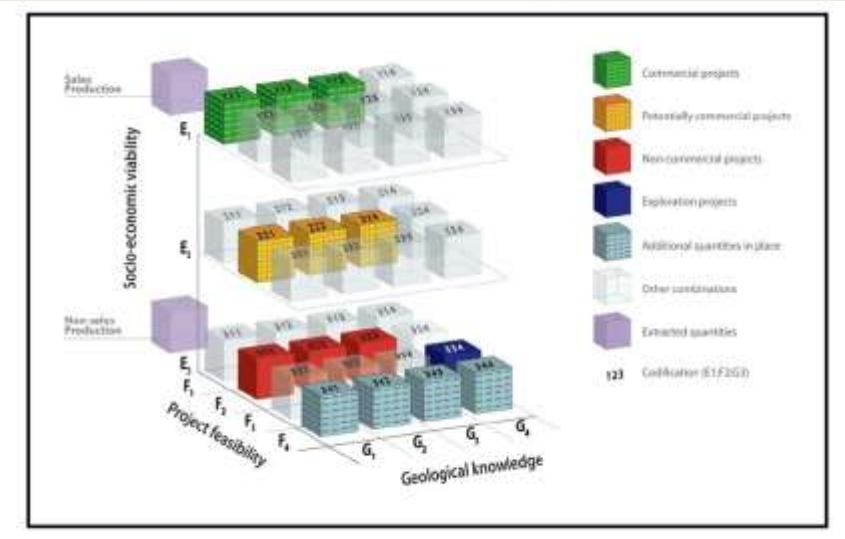
IAEA

International resource classifications

Committee for Mineral Reserves International Report (CRIRSCO)

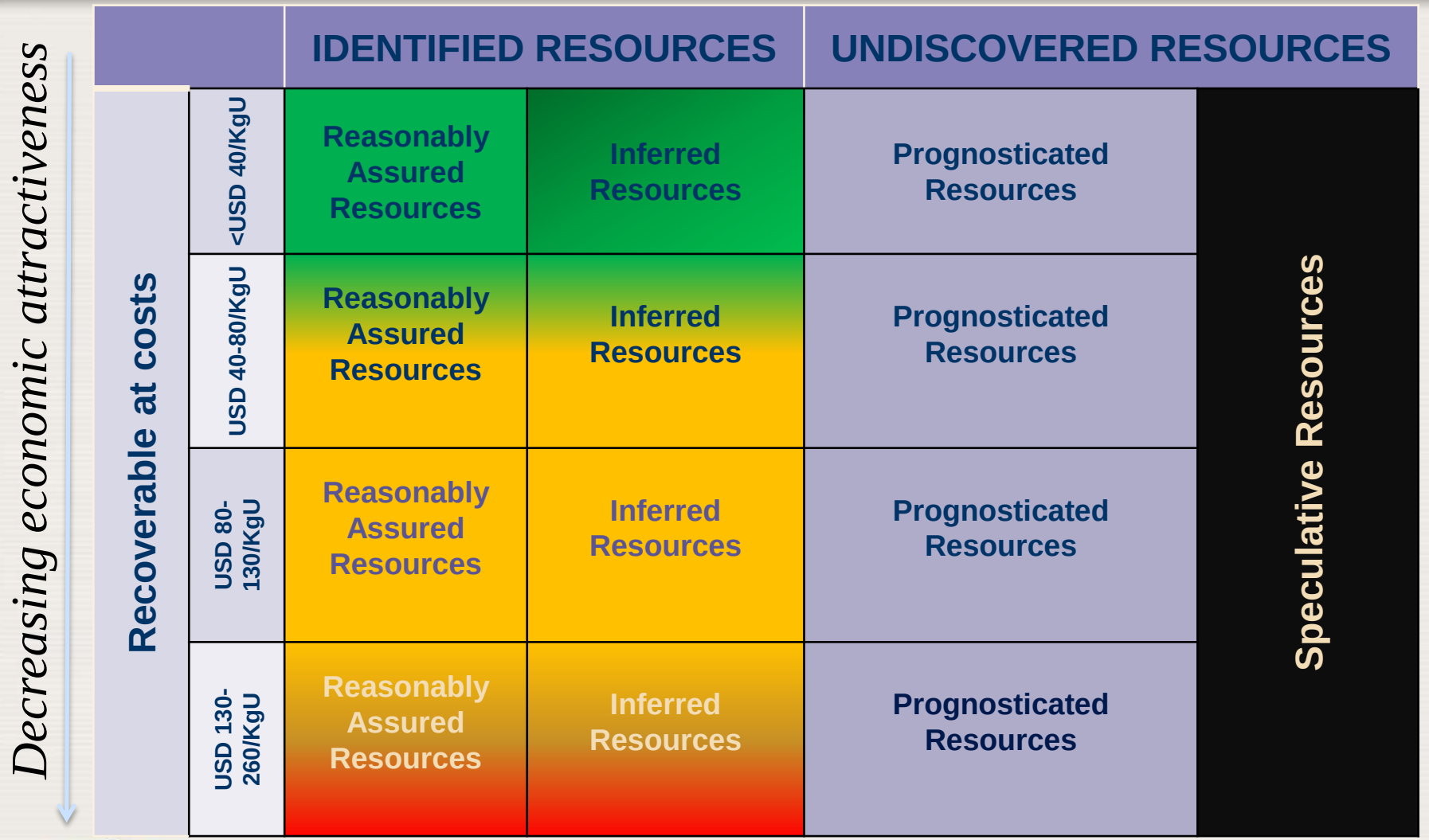


United Nations Framework Classification (UNFC-2009)



IAEA

NEA-IAEA Classification Scheme



IAEA

Resources ‘mapped’

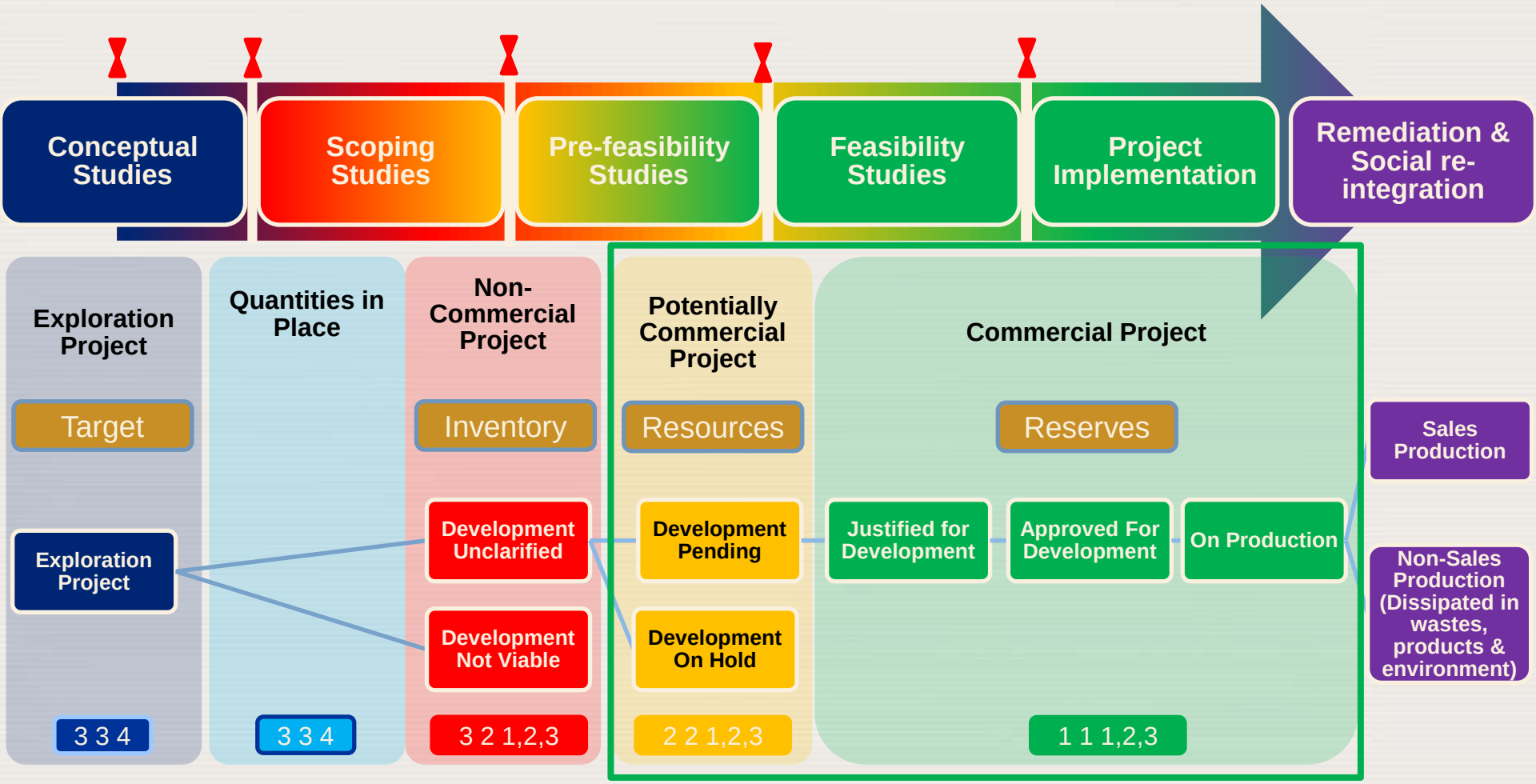
- United Nations Framework Classification (UNFC) used for alignment.
- “Uranium bridging document” under approval
- Also in alignment with CRIRSCO reporting (Public reporting for companies)

UNFC Classification					NEA/IAEA Classification	
UNFC Classes and Sub-classes		UNFC Categories				
Class	Sub-Class	E	F	G	Status	IAEA-NEA Categories
Commercial Projects	On Production	1	1.1	1,2	Existing	Reasonably Assured Resources (RAR)
	Approved for Development	1	1.2	1,2	Committed	
	Justified for Development	1	1.3	1,2	Planned	
Potentially commercial projects	Development Pending	2	2.1	1,2,3	Prospective	Identified Resources RAR IR*
	Development On Hold	2	2.2	1,2,3		
Non-commercial projects	Development Unclarified	3.2	2.2	1,2,3	Unclarified	Identified Resources RAR IR*
	Development not Viable	3.3	2.3	1,2,3	Not viable	
Exploration projects		3.2	3.1	4		Prognosticated Resources
		3.2	3.2, 3.3	4		Speculative Resources

*Inferred Resources

IAEA

U mining lifecycle and resources



Accurate and transparent management of essential materials throughout the lifecycle

IAEA

Uranium resources considered

Type of Deposit	Resources (tU)	% of Total
Phosphate	7,042,191	45.2%
Sandstone	2,364,768	15.2%
Polymetallic	1,365,024	8.8%
Metasomatite	812,413	5.2%
Unconformity	728,007	4.7%
Intrusive	691,102	4.4%
Metamorphite	655,761	4.2%
Black Shale	530,627	3.4%
Q-P Conglomerate	389,908	2.5%
Volcanic related	339,451	2.2%
Surficial	280,028	1.8%
Gold Tailings	143,888	0.9%
Granite related	138,610	0.9%
Carbonate	50,000	0.3%
Lignite-Coal	40,000	0.3%
Collapse breccia pipe	9,154	0.1%
Total	15,580,932	100.0%

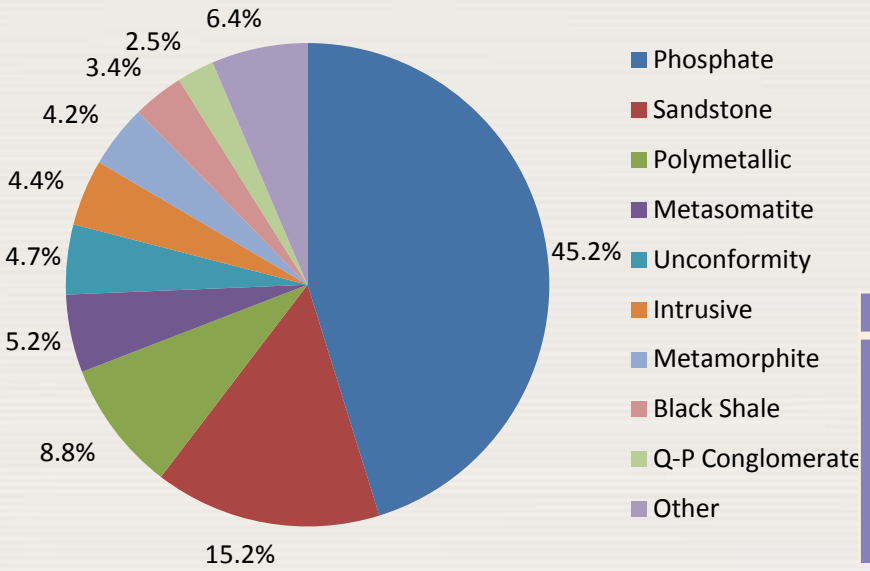
Unconventional Uranium Resources

Deposit type-subtype	Resources UDEPO (tU)	Grade (ppm)	IAEA UDEPO deposits	World deposits
Porphyry copper	100 000	10-40	7	691
Peralcaline complexes	393 210	50-250	13	125
Carbonatites	122 342	30-300	11	848
IOCG	2 308 602	30-250	14	> 100
Lignite and coal	7 358 112	1-500	33	1600
Black shale	1 489 147	10-200	44	Several hundred
Phosphates	13 553 900	50-150	50	1635
Total	25 325 313		172	5 - 6000
Sea water	4 500 000 000	3.3 ppb		

IAEA

Conventional U resources - 7 096 600 tU (The ‘Red Book’ 2011)

Resource distribution by type



Average grade (% U)	Resources (tU)	% of total
0 – 0.05	10 700 749	68.7
0.05 – 0.1	1 408 819	9.0
0.1 – 0.3	2 799 487	18.0
0.3 – 1.0	249 566	1.6
> 1.0	422 311	2.7

Size of deposit (tU)	Number of deposits	Resources (tU)	% of total resources
< 1 000	36	19 850	0.1
1 000 – 5 000	112	286 692	1.8
5 000 – 10 000	82	555 587	3.6
10 000 – 20 000	56	786 802	5.0
20 000 – 50 000	57	1 747 994	11.2
50 000 –100 000	23	1 563 014	10.0
>100 000	19	10 620 993	68.2
Total	385	15 580 932	100.0

IAEA

Production methods

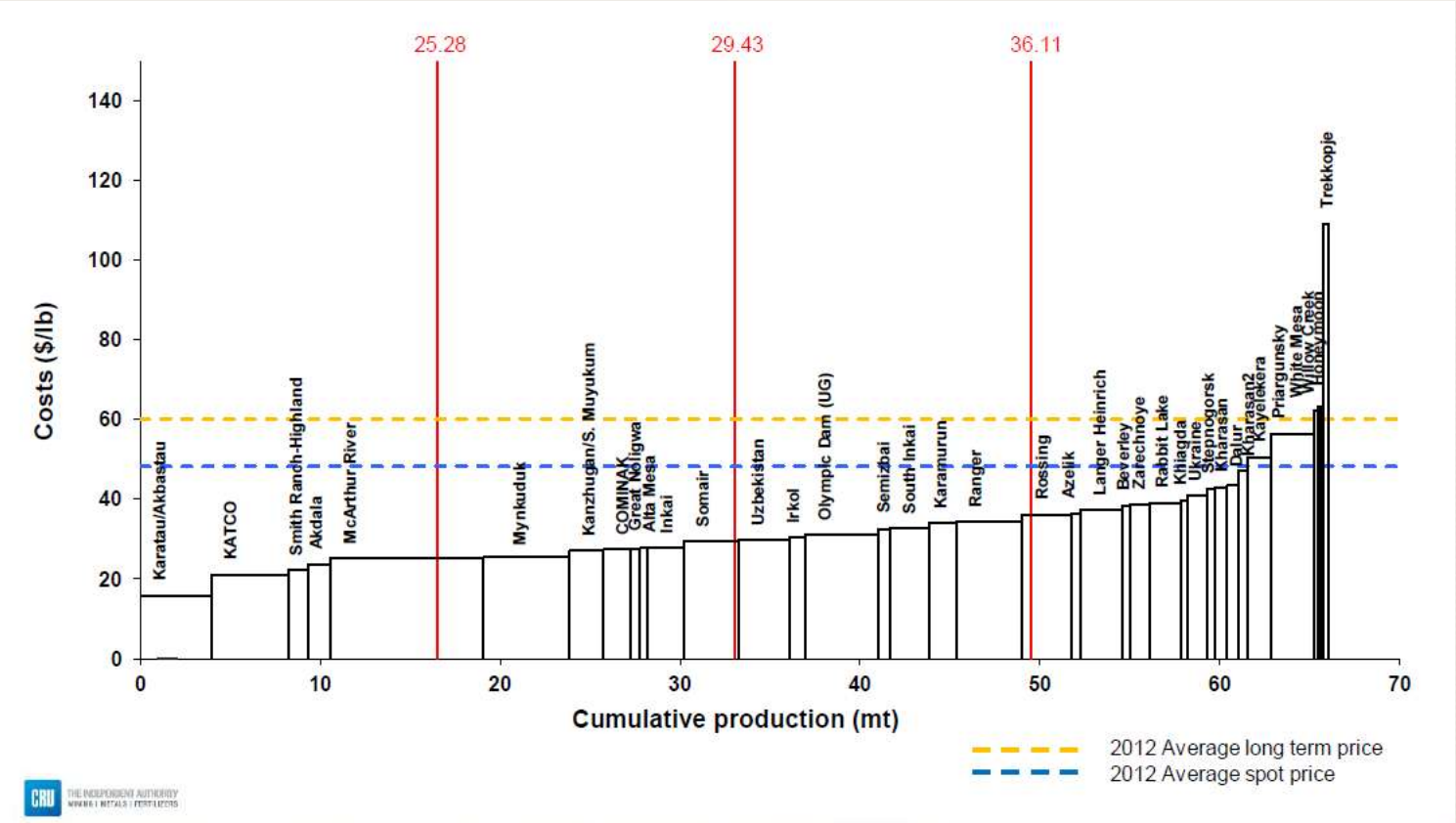
Mining Method	Resources (tU)	% of total
Open-pit (OP)	10 854 111	69.7
Underground (UG)	2 840 520	18.8
Open-pit / Underground (OP / UG)	479 650	3.1
In situ leaching (ISL)	1 261 686	8.1
Other (Mine waste, Tailings)	144 965	0.9
Total	15 580 932	100.00

	Resources (tU)	% of U 2060 resources
Phosphate	7 042 191	45.2
Cu, Au, Ag (Olympic Dam)	1 365 024	8.8
Gold (Quartz pebble cong.)	389 908	2.5
Other (Rare earths, Cu, Ni, …)	268 591	1.7
Total	9 065 714	58.2

IAEA

Production costs

Cost category		Resources (tU)	% of total
L	< US$ 80 / kgU	2 240 217	14.4
M	US$ 80 – 130 / kgU	2 426 156	15.6
MH	US$ 130 – 210 / kgU	8 115 118	52.1
H	US$ 210 – 260 / kgU	1 777 272	11.4
VH	> US$ 260 kgU	1 022 169	6.6
Total		15 580 932	100.0



IAEA

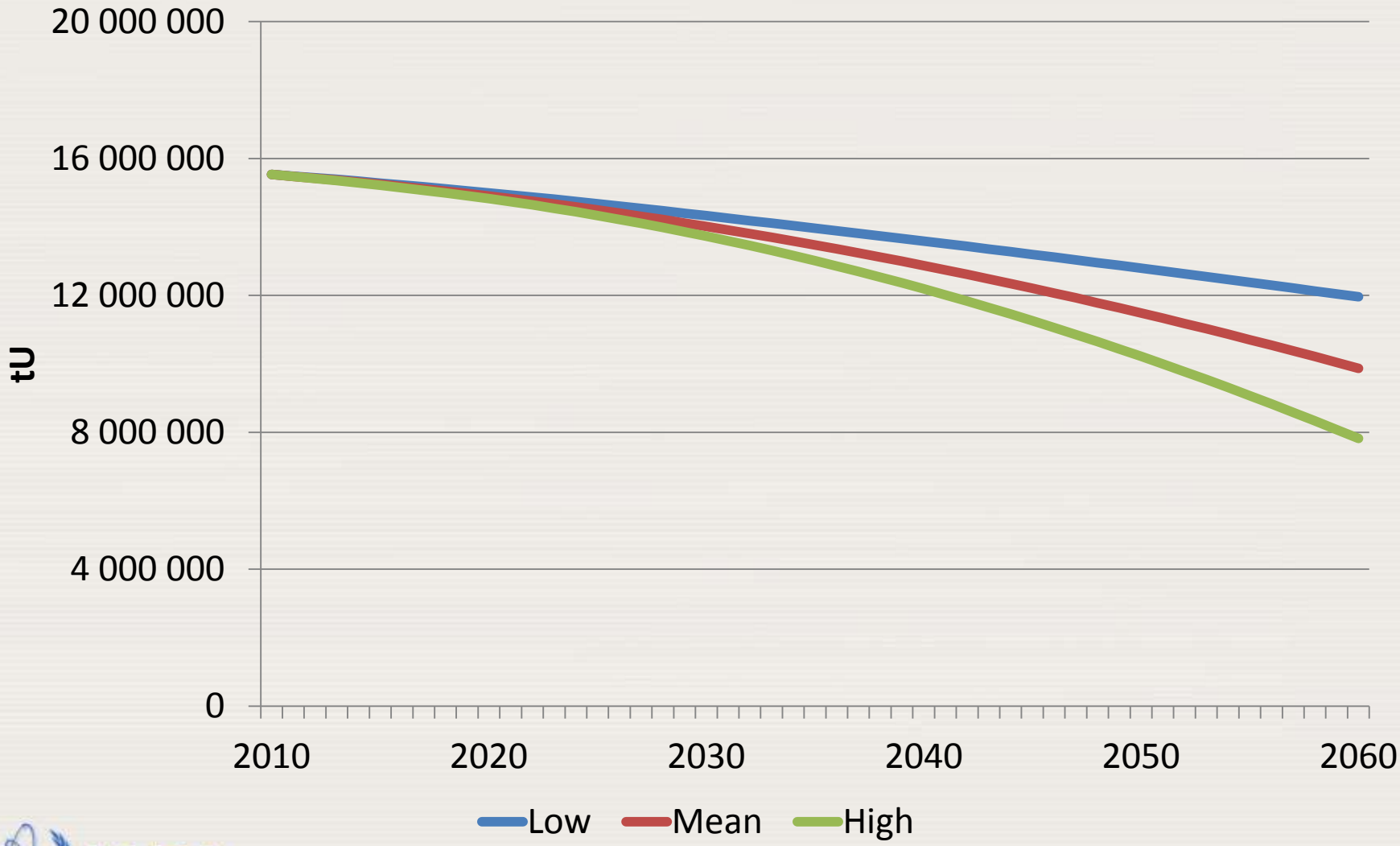
Mining capacity

Mining capacity (tU/yr)	Number of deposits	Resources (tU)	% of total resources
0-200	58	267 432	1.7
200-400	126	963 876	6.2
400-1 000	101	5 257 905	33.7
1 000 – 2 000	61	5 068 517	32.5
2 000 – 4 000>4 000	28	1 371 437	8.8
	11	2 651 765	17.0

Project status	Number of production centers	Total mining capacity (tU/yr)	Associated resources (tU)	Average grade (%U)
Existing	78	106 862	2 199 433	0.055
Planned	60	42 434	1 194 350	0.032
Prospective	247	150 047	12 187 149	0.015

IAEA

Remaining resources



IAEA

Conclusion

- Existing uranium resources **will not constrain the use of nuclear power** in the next half century.
- However, **constraints on nuclear fuel supply may, from time to time, develop in the form of production capability or cost.**
- It seems possible that an unforeseen rapid push for more nuclear capacity might require **a surge in uranium production that could not be met due regulatory and environmental constraints.**
- It is considered very unlikely that any reactor would ever be shut down for a lack of fuel resulting from a shortage of natural uranium.

IAEA

Thank you

Harikrishnan TULSIDAS | Nuclear Technology Specialist|
Section of Nuclear Fuel Cycle and Materials | Division of Nuclear Fuel Cycle and Waste Technology | Department Nuclear Energy |
International Atomic Energy Agency | Vienna International Centre, PO Box 100, 1400 Vienna, Austria |
Email: T.Harikrishnan@iaea.org | T: (+43-1) 2600-22758 | M: (+43) 664-736-11790 | F: (+43-1) 2600-7 |
Follow us on www.iaea.org

IAEA