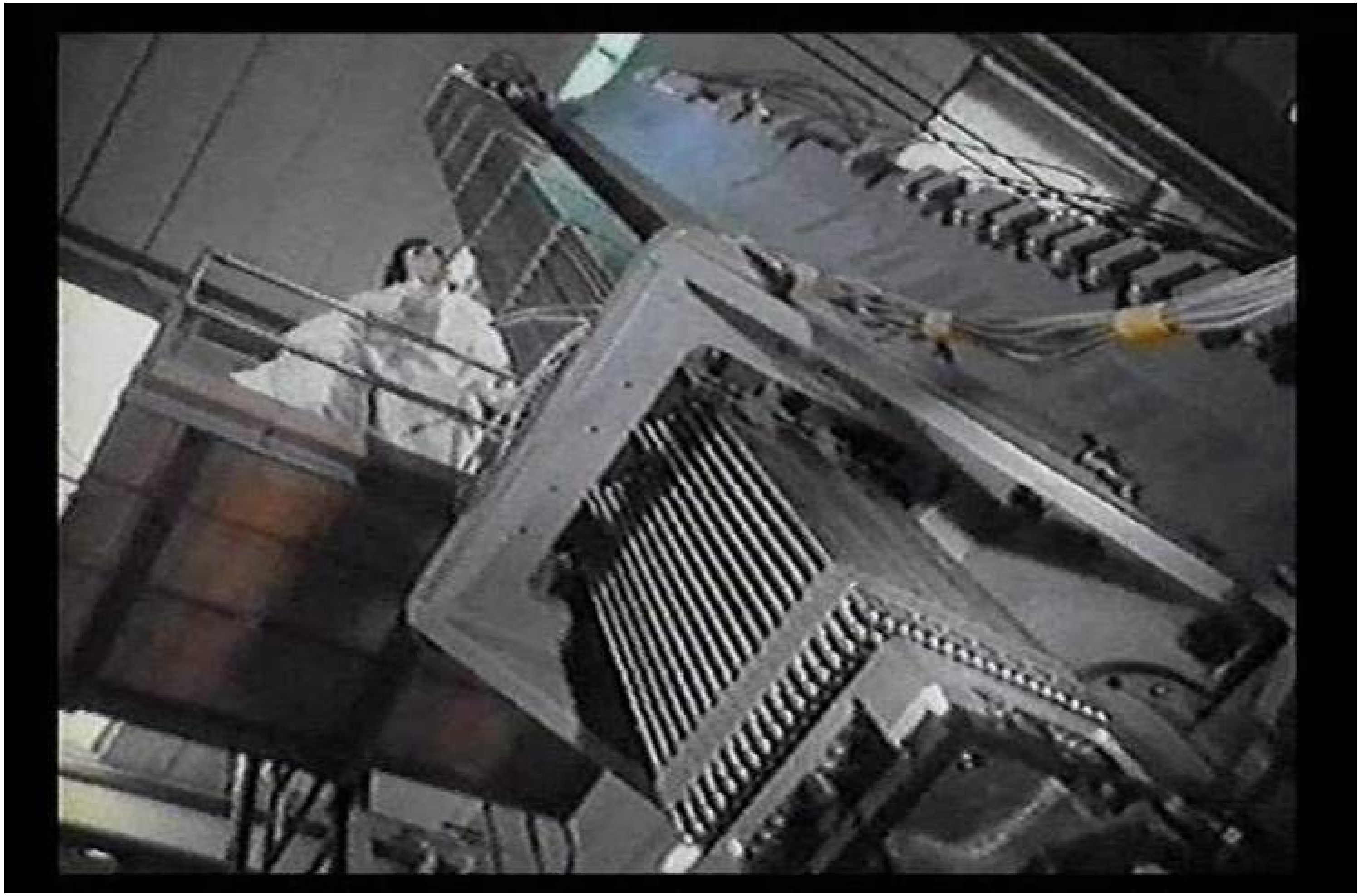
International Atomic Energy Agency

The Nuclear Fuel Cycle and its Market
An Overview

Hans Forsström, Director
Division of Nuclear Fuel Cycle and Waste Technology

Nuclear Fuel Cycle

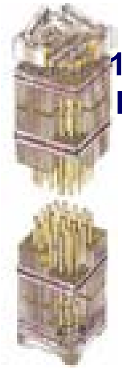
Fuel Assembly



Typical Fuels

37 Fuel Elements
CANDU/PHWR
Zircaloy clad,
Natural UO_2 Fuel

Ceramic Fuel Pellets



17x17
PWR

9x9
BW
R

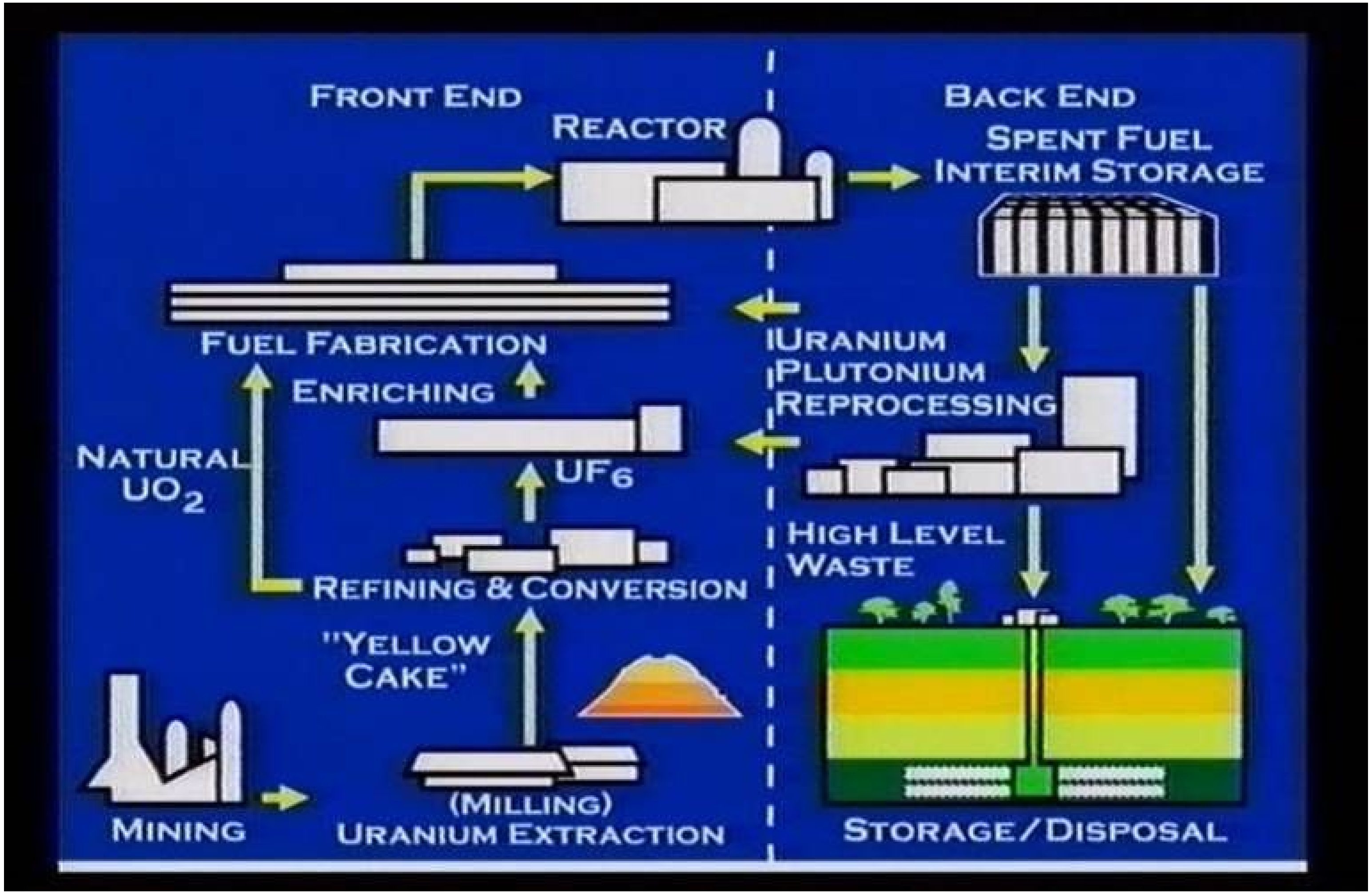
Zircaloy clad
Slightly Enriched Uranium
(<5%U^{235})UO_2

312 Fuel
Elements

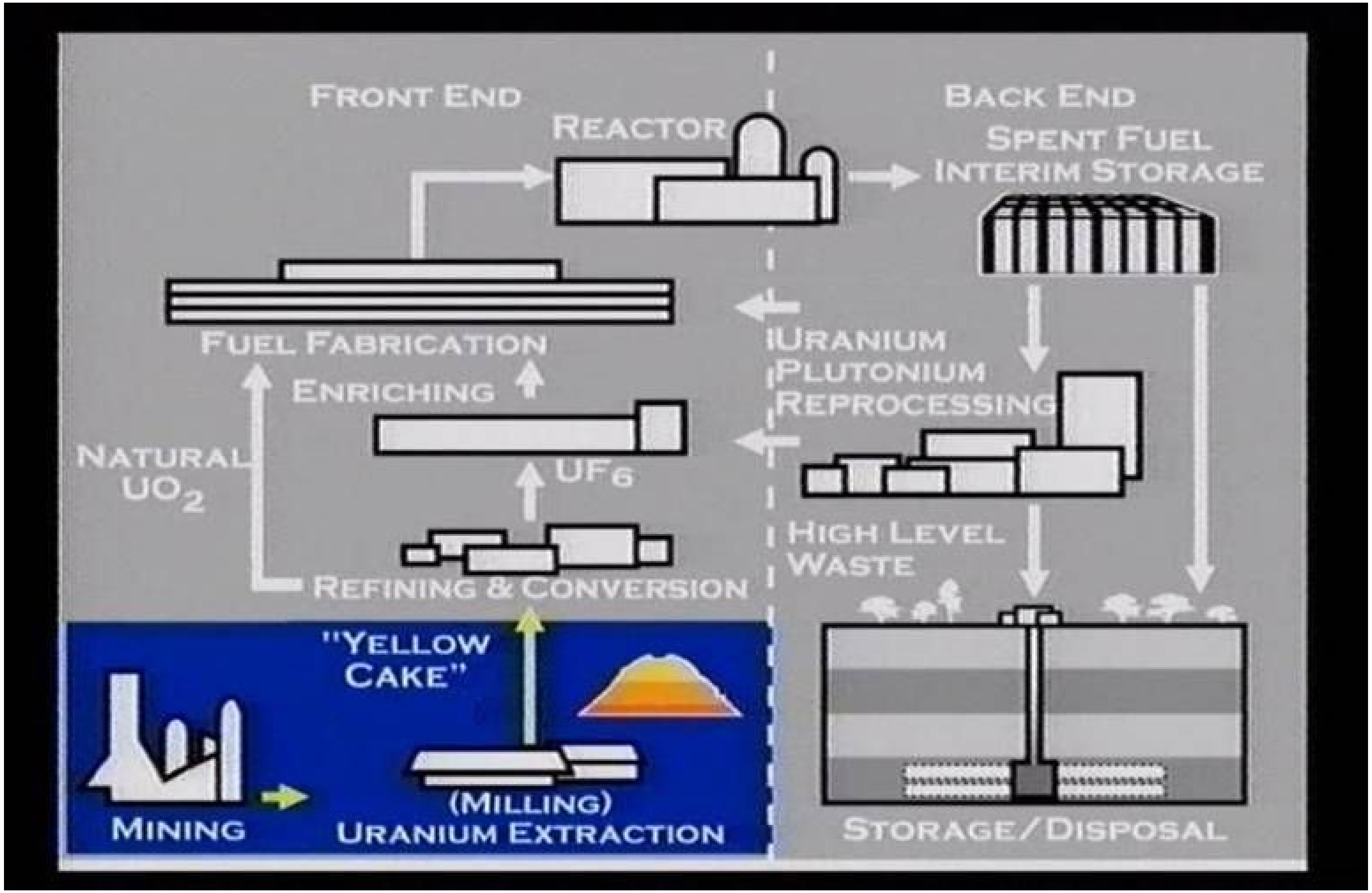
VVER-1000
Zr-1%Nb clad
Slightly Enriched Uranium
(<5%U^{235})UO_2

Fast Breeder Reactor FUEL
Stainless Steel clad, (U, Pu)O_2
(20-25% Pu O_2)

The Nuclear Fuel Cycle



Uranium Mining and Milling



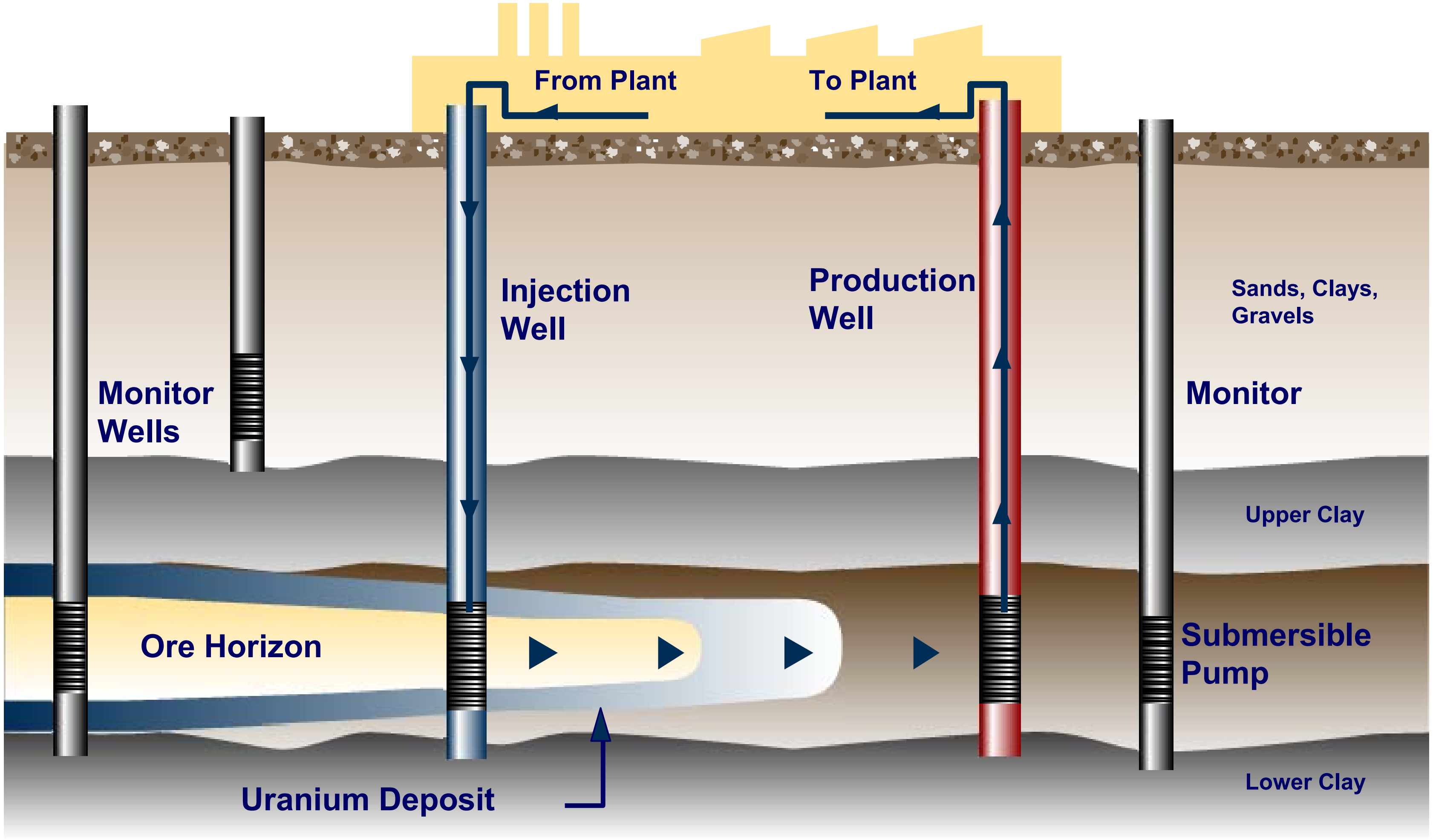
Uranium Mining

Open Pit Mining
Rossing Mine, Namibia

Underground Mining
Palabora, South Africa (RTZ photo)

In Situ Leach Mining, Beverley, Australia
(image: Heathgate)

ISL Mining – Wellfield (Cross Section)

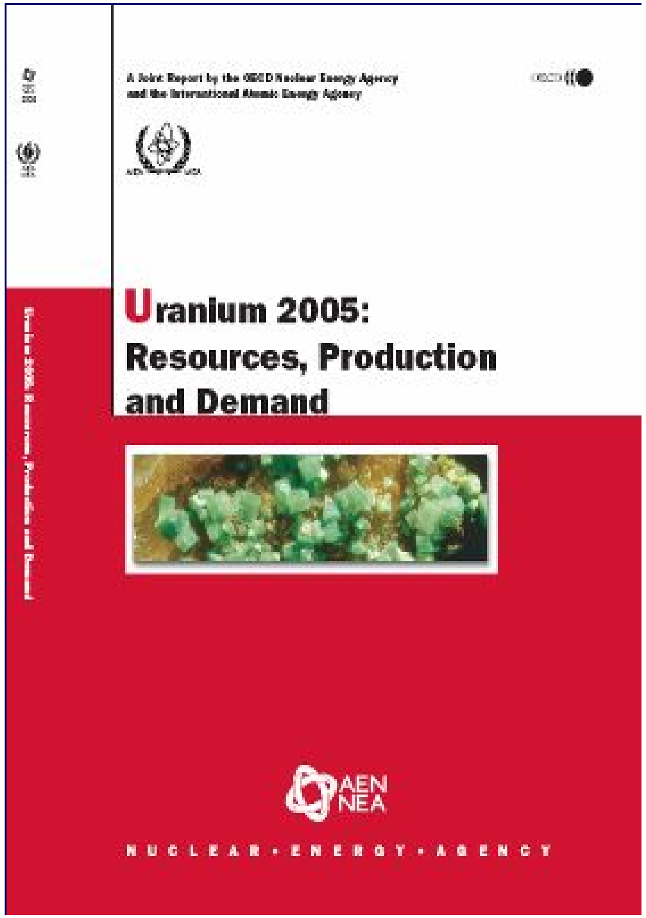


Yellow Cake

Final Product of Milling Step – 70 to 80 % Uranium

Uranium Resources: Red Book 2007

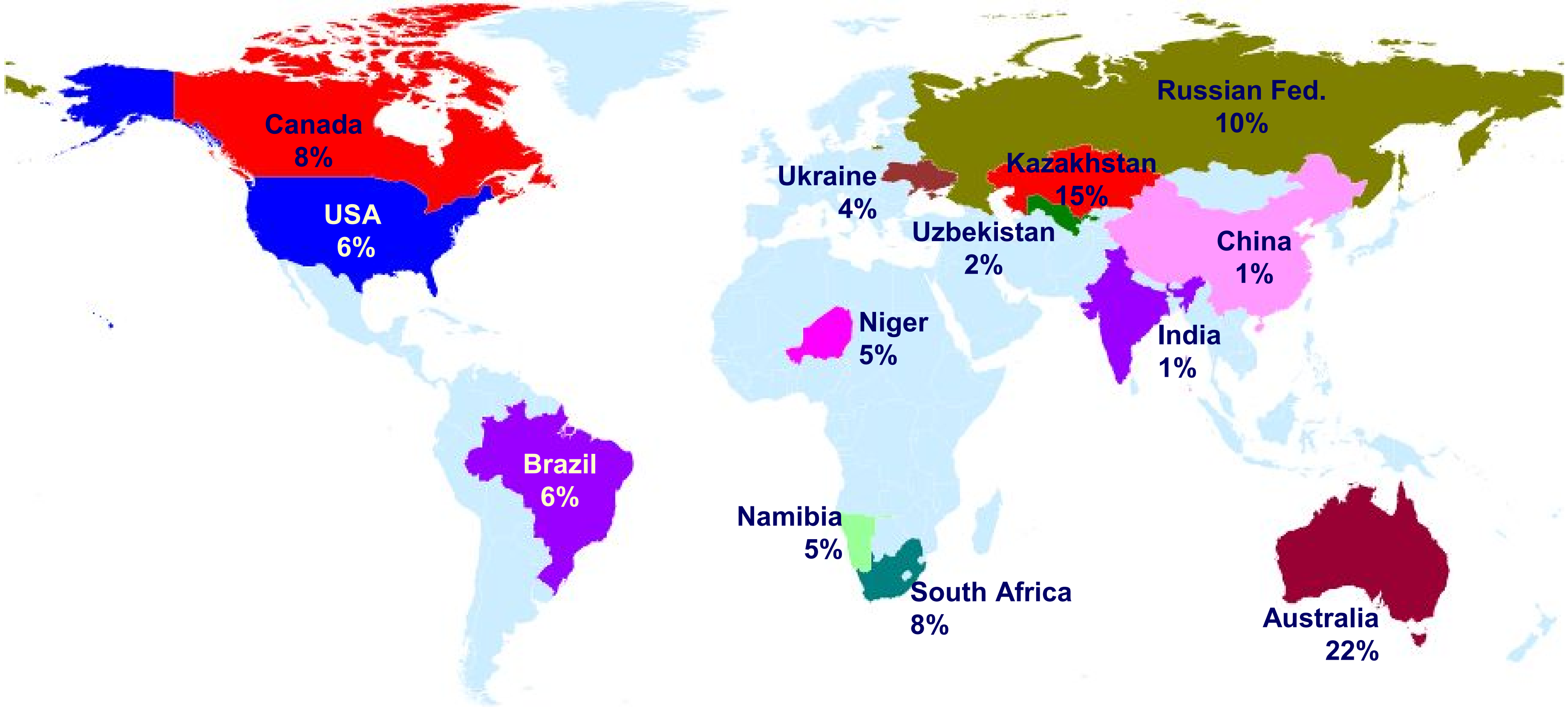
- **Is there enough?**
- **Are supplies secure?**
- **Can we meet demand?**



Distribution of
Identified Uranium Resources Worldwide

(Is the Supply Secure?)

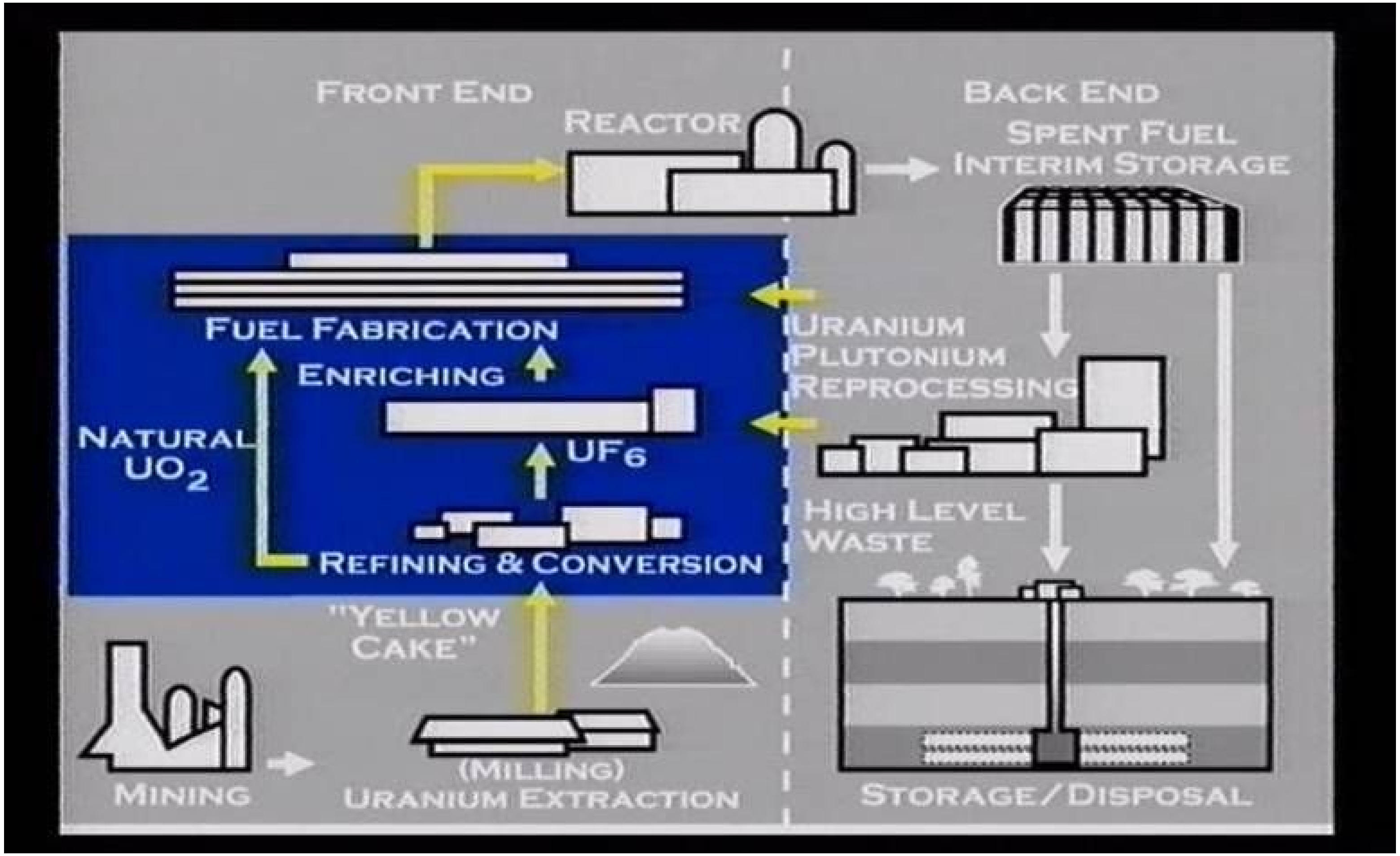
Total Identified Resources: 5.55 Mt (2007)



Uranium Market

- Competitive market – several countries
- 1000 MWe reactor requires about 200 tU/y
- 66 500 tU required in 2006
- 40 000 tU produced
- Remainder from secondary sources
- Uncertainties in medium term
- Spot price volatility
- Mainly long term contracts

Conversion, Enrichment and Fuel Fabrication



Uranium Conversion

- **Converts yellow cake (U_3O_8) to UF_6 for enrichment or UO_2 for fuel manufacturing**
- **Reconverts enriched UF_6 to UO_2**
- **Competitive market – several countries**
- **Balanced market**
- **Small component of the cost**

Enrichment: Gaseous Diffusion Process

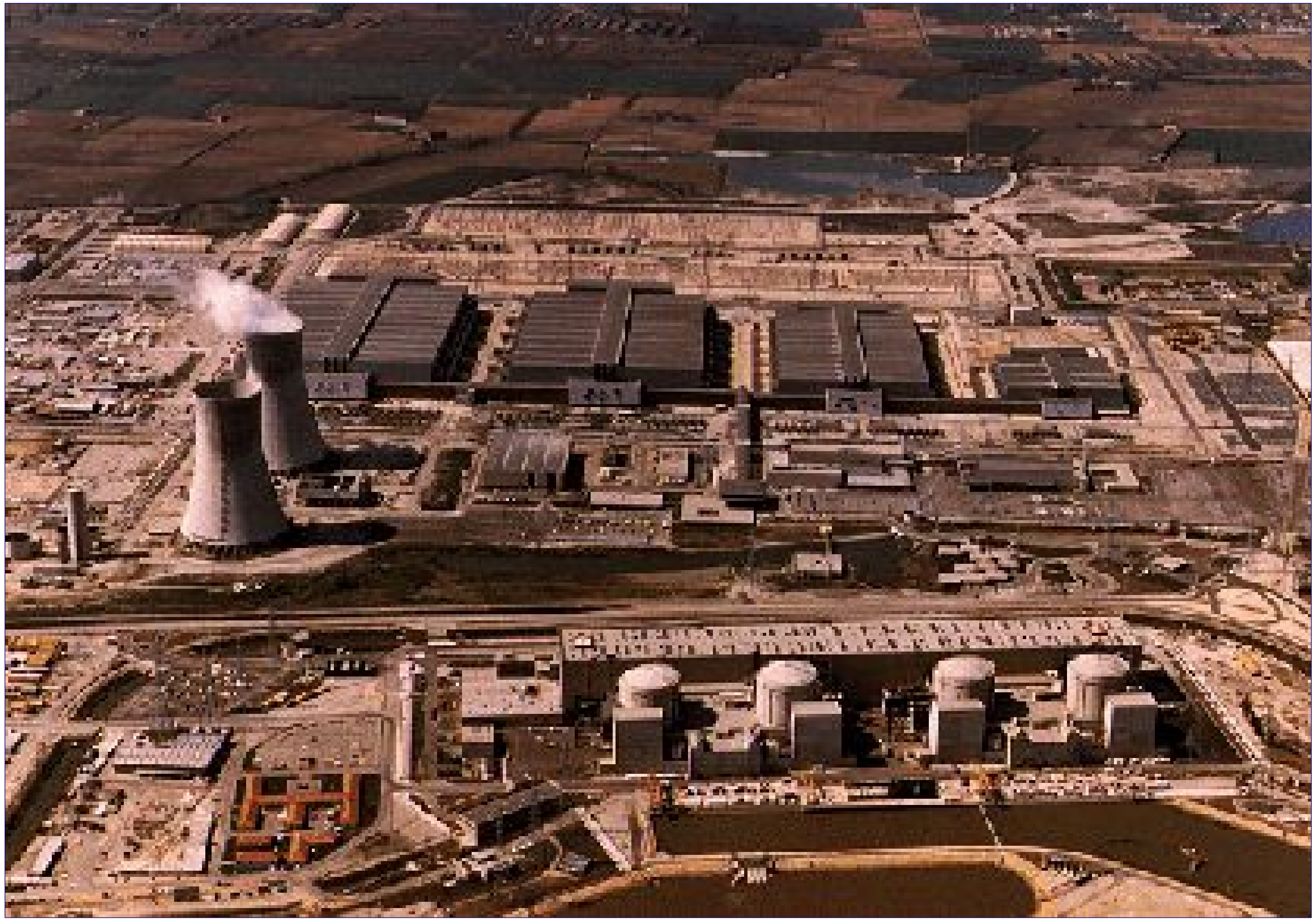


Image: Areva

Georges-Besse Enrichment Plant in France

Enrichment: Centrifuge Process

A Bank of Centrifuges at a Urenco Plant
(image: Urenco)

Uranium Enrichment

- Uranium enrichment two technologies - diffusion and centrifuges
- Large enrichment facilities in F, D, NL, RF, UK, USA, CH and J
- Competitive market – fairly stable prices
- Demand 40 million SWU – 1000MWe = 100 kSWU
- World capacity larger – new capacity under construction
- Small spot market – mainly long term contracts
- Secondary sources – downblending HEU, re-enriching tails

Uranium Oxide after Conversion

Image: Cameco

UO_2 - Pellets and Fuel Assembly

Image: Cameco

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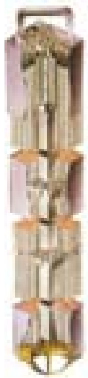

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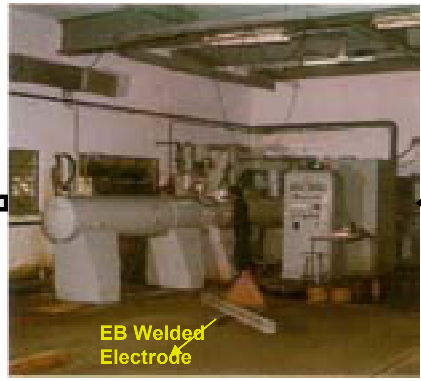
FROM Zircon Sand to Zirconium Alloy Ingots at NFC, Hyderabad

Zircon Sand

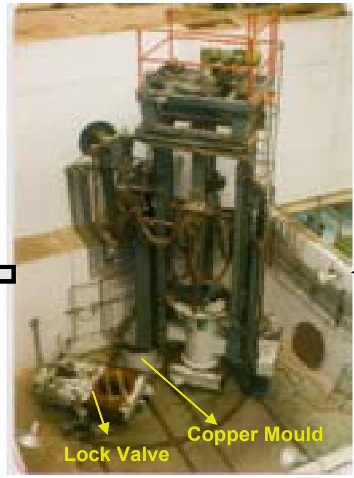
Hf-free ZrO_2 Powder

Nuclear Grade Zr Sponge

Compaction of Zr Sponge + alloying elements Briquettes



Electron Beam Welding of Briquettes to form Consumable Electrode



Vacuum Arc Melting Furnace using Consumable Electrode

Zirconium Alloy Ingot
Max. size: 350 mm dia x 2 m height

Fuel Manufacturing

- Highly technical product with a lot of IPR
- Quality requirements very high
- Fuel adapted to specific reactors and to reactor operational status (including existing fuel and operating history)
- Each fuel batch requires licensing
- Fuel supply often coupled to reactor supply
- Change of suppliers possible, but takes time
- Strategy of many utilities to change supplier from time to time
- More than one supplier available for most fuels

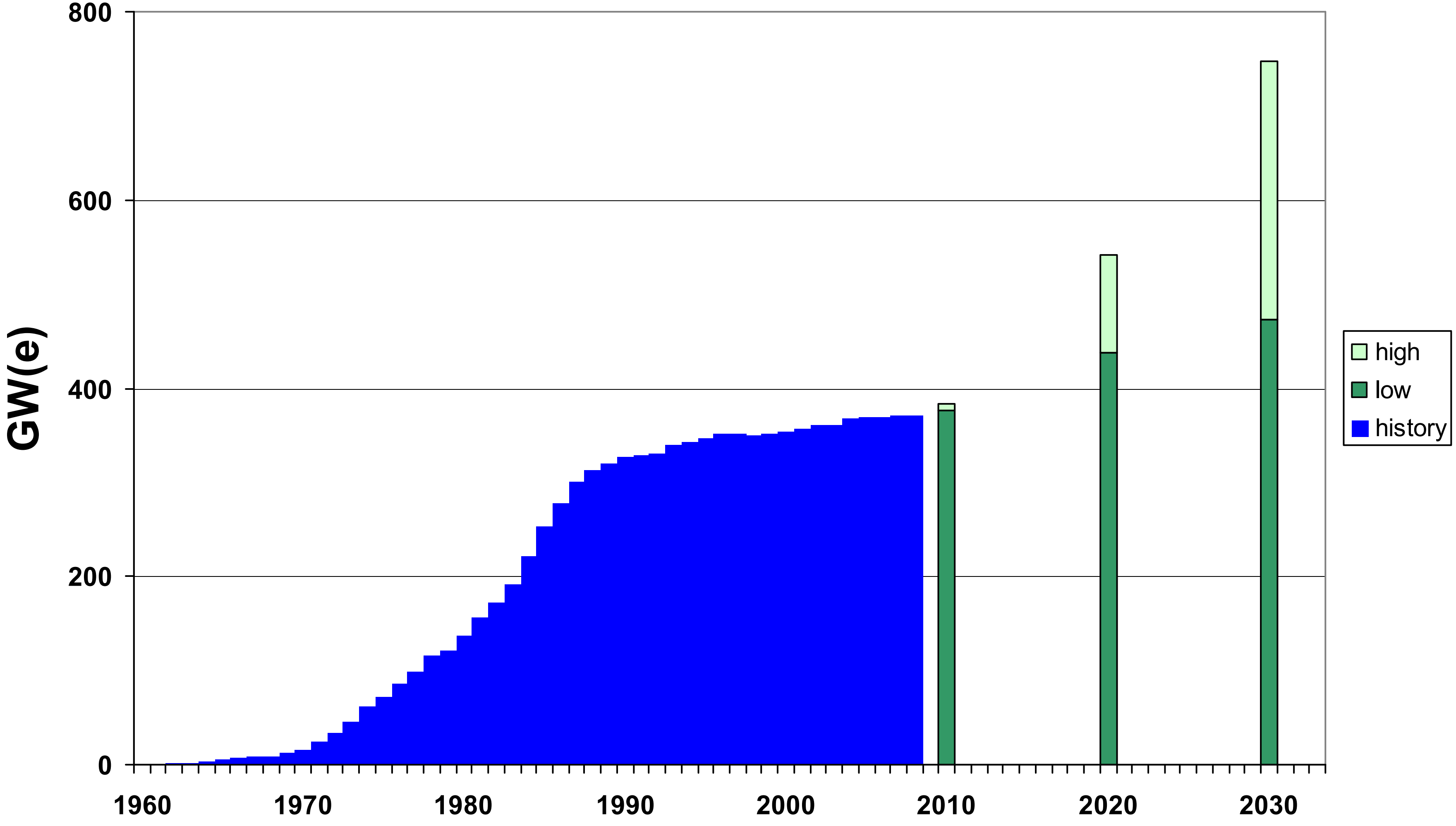
Fuel Manufacturing (cont.)

- World demand 12000 tU/y
- 1000 MWe PWR requires 20 - 25 tU/y (depending on enrichment level)
- 1000 MWe PHWR requires about 130 tU/y (natural uranium)
- World manufacturing capacity sufficient

Utilities Purchasing Strategies

- Some buy each component of the fuel cycle separately (uranium, conversion, enrichment, manufacturing)
- Diversification of suppliers in each group
- Some buy full fuel assemblies with enriched uranium
- Significant amount of transports involved and often included in the contracts above
- A mixture of long term contracts and spot contracts

Nuclear Power - IAEA's Projection



Fuel Cycle Needs for IAEA Scenarios

	2008	2030	
		Low	High
Nuclear power (GWe)	373	473	748
Natural U (ktonnes)	67	65-80	100-125
Conversion UF6 (ktonnes U)	64	60-75	95-120
Enrichment (MSWU)	46	55-70	85-110
Fuel fabrication (ktonnes U)	12	11-13	17-20
MOX fabrication (ktonnes HM)	0.2	0.2	0.5
SF discharge (ktonnes HM	12	11-13	18-21
SF reprocessing (ktonnes HM)	1.5	1-2	4-6

IAEA Databases Related to Nuclear Fuel Cycle

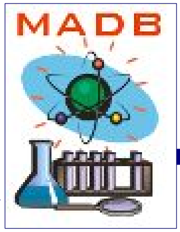
http://www-nfcis.iaea.org
http://www-newmdb.iaea.org

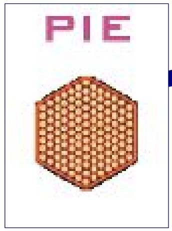
Information Sources

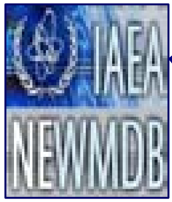
- Member States (Contact Points)
- Consultants
- IAEA Meetings
- Reliable Publications

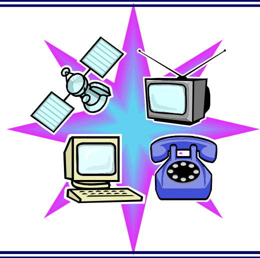
Inputs

- Nuclear power projections
- Nuclear fuel cycle options
- Reactor physics calculations







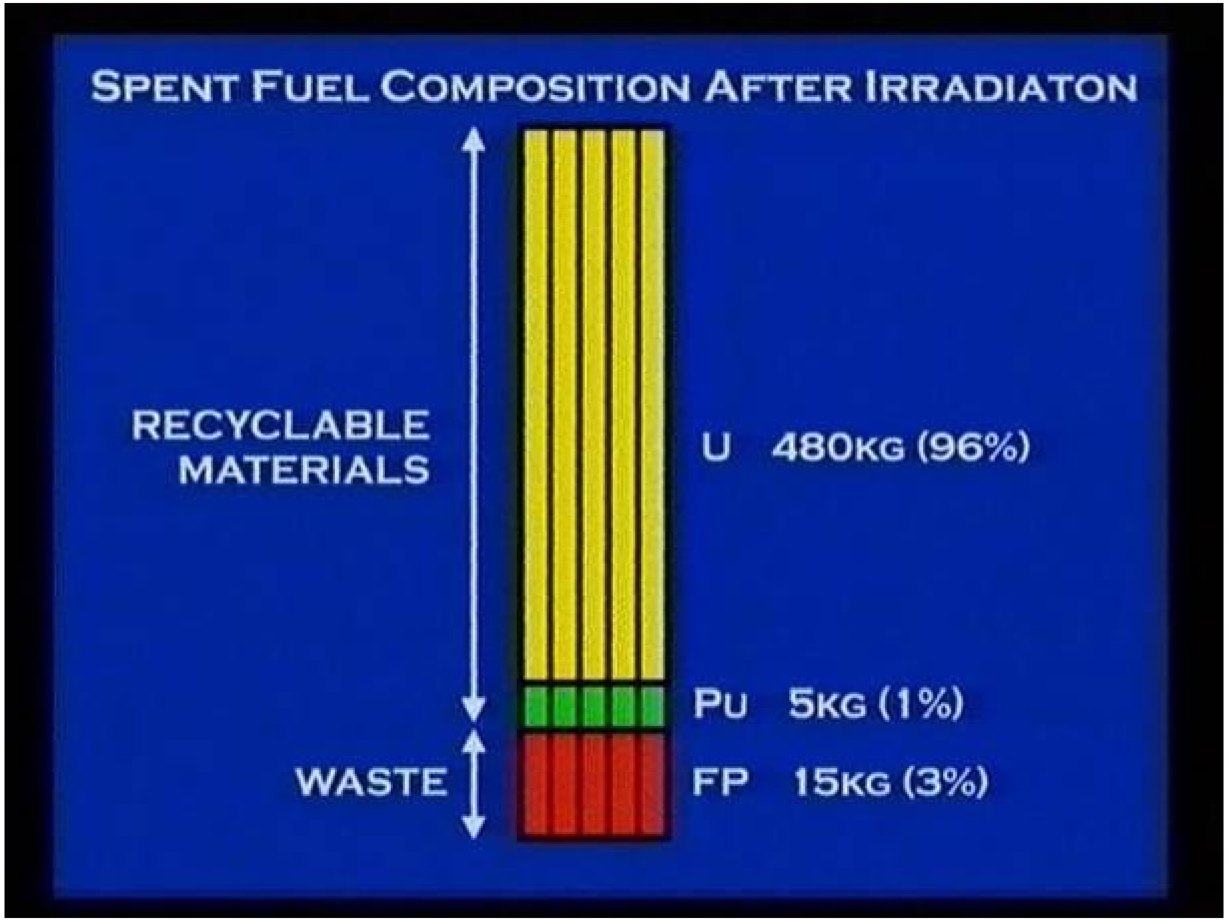


Internet

- Navigation through facilities
- Search capabilities
- Summary reports for country specific or worldwide
- Country nuclear fuel cycle profiles
- Long term nuclear fuel cycle requirements for different scenarios

NFCIS:	Nuclear Fuel Cycle Information Systems
MADB:	Minor Actinide Property Database
PIE:	Post Irradiation Examination Facilities Database
VISTA:	Nuclear Fuel Cycle Simulation System
NEWMDB:	Net Enabled Waste Management Database

Spent Fuel Composition after Irradiation



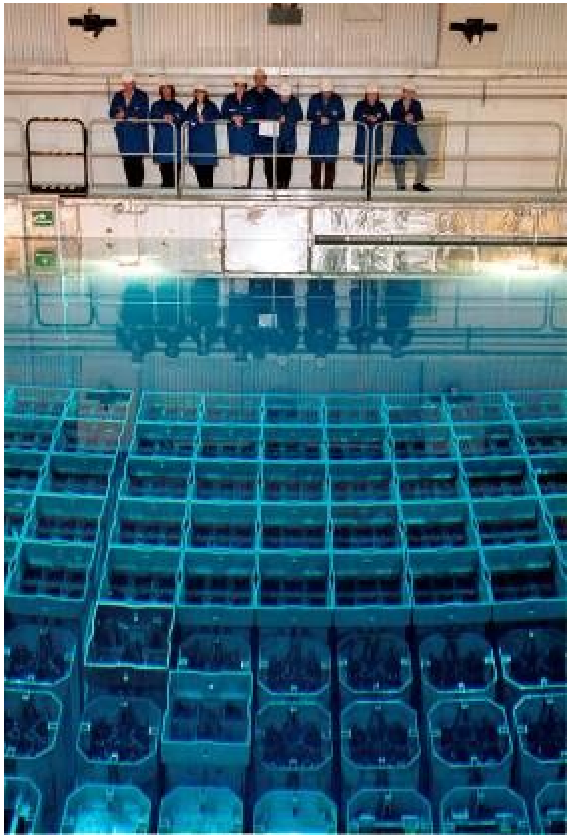
Basic Options for Spent Fuel Management

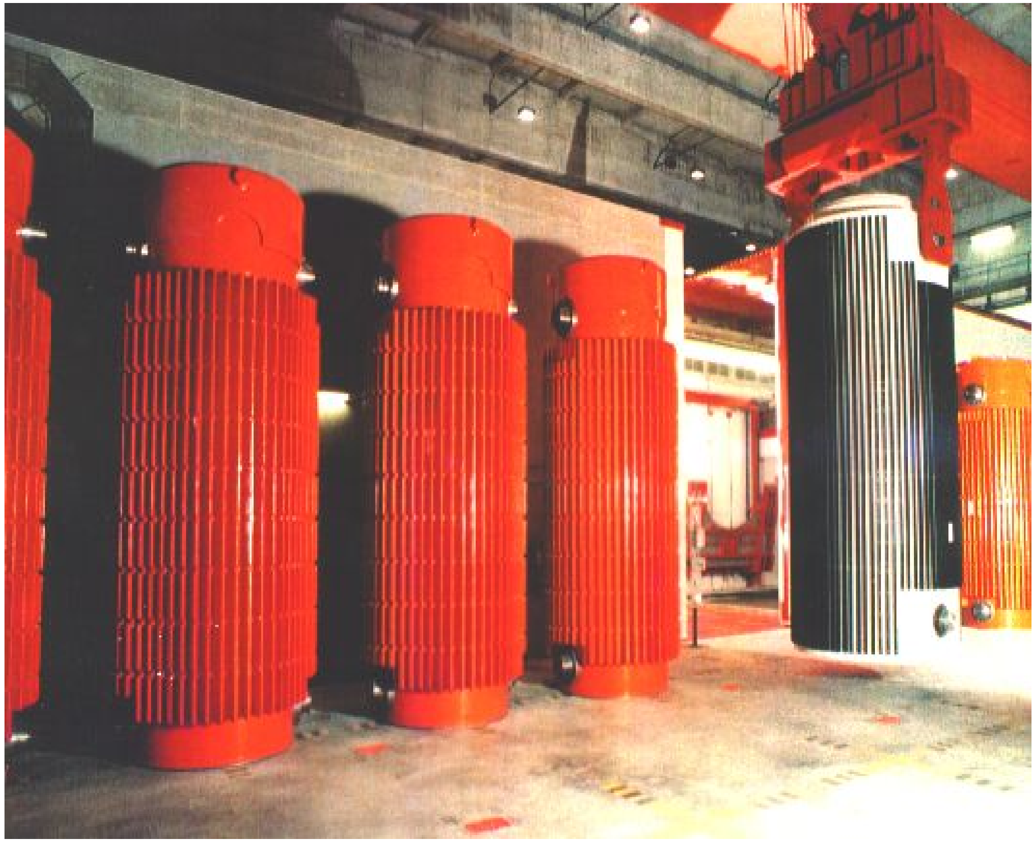
1. ***Classical closed cycle*** **– spent fuel reprocessed Pu+U recycled and waste disposed**

2. ***Once-through cycle*** **– spent fuel stored and then disposed**

3. ***Advanced closed cycle*** **– spent fuel reprocessed Pu+U+actinides recycled and waste disposed**

Storage of Spent Fuel





Storage at the reactors or in separate local or national facilities

Spent Fuel Reprocessing

Spent Fuel → **Chemical and Physical Processes** → U, Pu

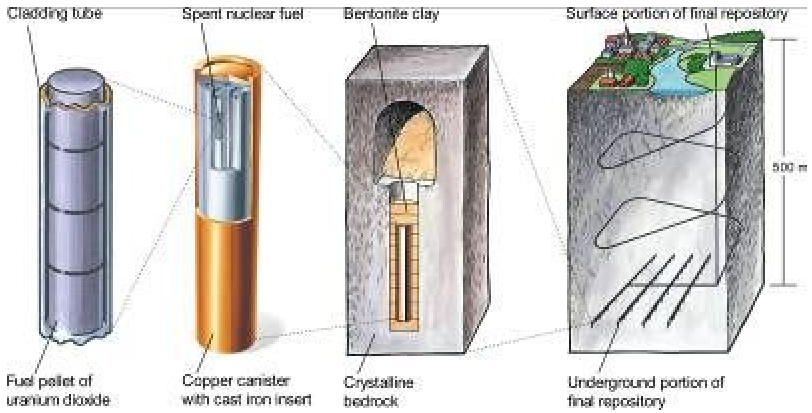
↓

Waste

Commercial reprocessing in a few countries' markets exists – 15 % of fuel is reprocessed

Disposal of HLW and Spent Fuel

- **Technical solutions are available for geological repositories**
- **No disposal facility for HLW or spent fuel in operation**
- **Good progress for repositories for HLW or spent fuel in USA, Finland, Sweden and France, but no repository until ~2020**
- **So far only national approaches**



Summary

- **Nuclear fuel production involves several steps: Mining and milling, conversion, enrichment, re-conversion and fuel assembly manufacturing**
- **Up to enriched UF6 a commodity – manufactured fuel highly technological**
- **Separate markets exist for each step**
- **Production/demand in balance today except for uranium – secondary supplies cover balance**
- **Fuel services supplies expected to continue match demand**
- **Strong spot price fluctuations in uranium – other steps more stable**
- **Back end services less or not developed**

IAEA

Thank you for your attention

…atoms for peace.