International Atomic Energy Agency

Formulating Criteria Related to Fuel Cycle Policy and Waste Management

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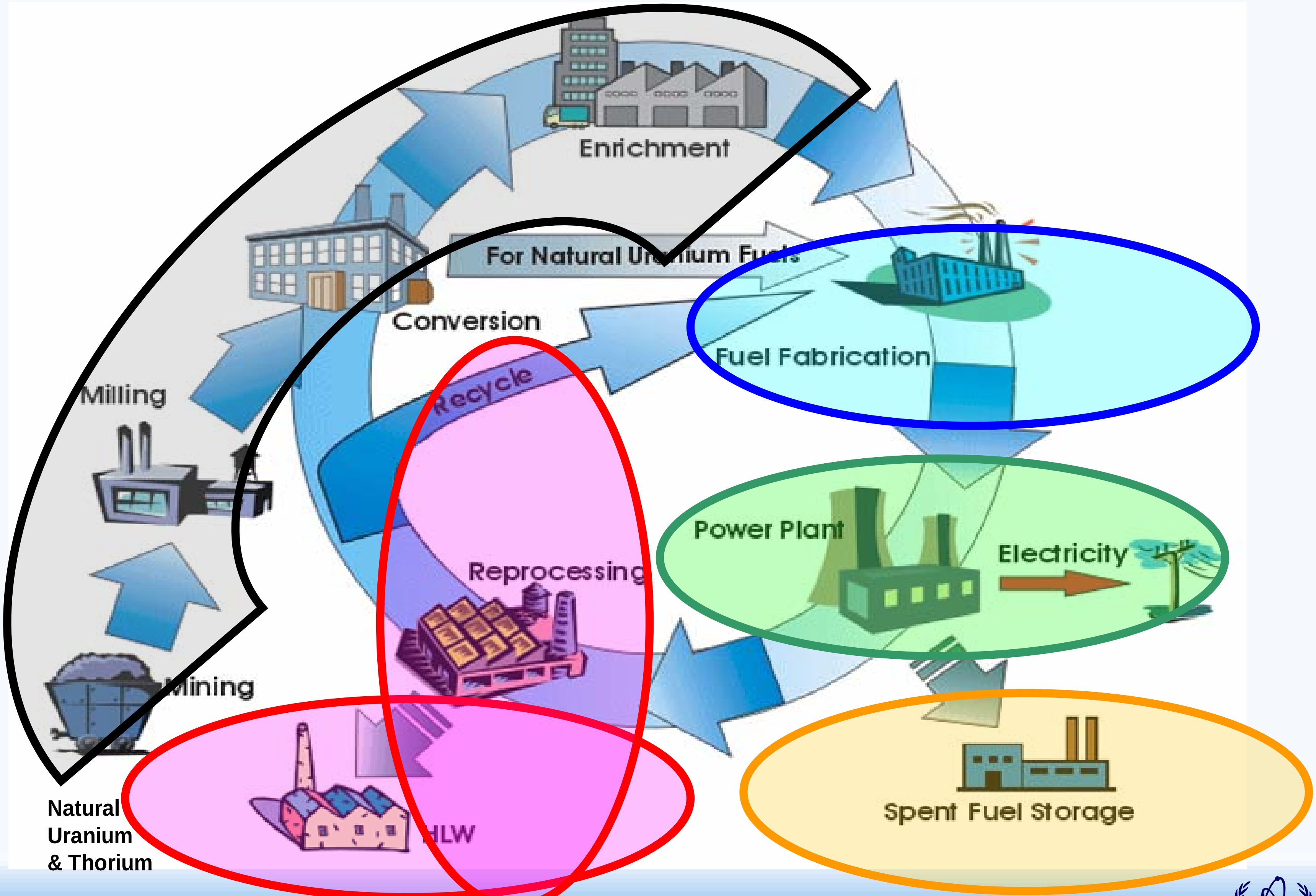
Sustainability of Operation

- Fuel cost is relatively low (5 to 15% of Levelized Unit Energy Cost), but no fuel no operation;
- Assurance of fuel supply is essential to sustainable operation of NPP throughout its plant life;
- The fuel cycle business is international:
  - It is very unlikely that a country will expect - or want to have all the fuel cycle facilities available in the country. Only Russia has a capability for a closed fuel cycle operating within its own territory.

The Nuclear Fuel Cycle



Fuel cycle business is international

For example:
uranium mined in Australia
can be converted in Canada,
enriched in the Netherlands,
then fabricated as fuel in Sweden
For irradiation in a reactor in Germany

Spent fuel has gone from Germany
for reprocessing in the United Kingdom
and back as MOX and HLW to Germany

Worth mentioning TRANSPORT!

Key players

Miners - Sell Uranium yellowcake

Converters - Prepare uranium for processing

Enrichers - Enrich fuel for use – proliferation?

Vendors - Will sell NPPs and fuel services

Utilities - Operate NPPs, own the waste!

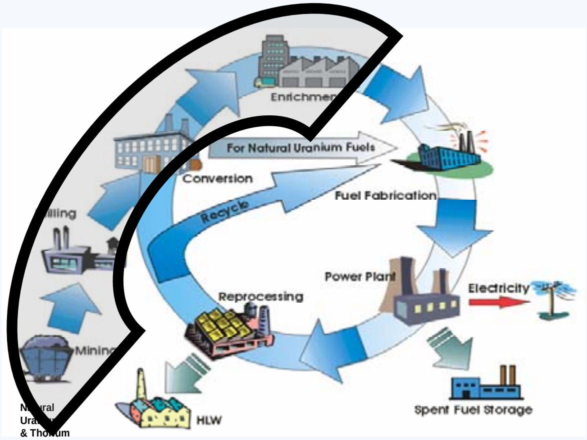
Reprocessors - Waste handling, recycle fuel?

Regulators - Licensing and control

Waste Management – Essential!

Commercial “commodities”

Focusing on Uranium Fuel:



- Mined uranium
- Conversion
- Enrichment
- UO_2 powder

These items are available on the market and are suitable as required for any reactor system

Miners

Total world production:

2005: 42,000tU 2006: 39,500tU 2007: ~43,500tU

Canada and Australia account for around 44% of the uranium mined today, with Kazakhstan, Russia, Niger, Namibia and Uzbekistan sharing another 44% of the market.

Future production centres are available and expansion is expected in Kazakhstan, Australia, Canada, Russia, Niger, Namibia and a new producer; Malawi

Miners – Ranger Mine in Australia

Miners

Currently, only around 70% of the uranium used in power reactors comes from freshly mined material, the rest comes from a secondary market based on ex-military material and other recycled materials.

However, the currently identified resource in the ground is around 5,550,000tU and would last for 90 years at current demand levels

This is the officially reported resource only, and the potential is much higher

Uranium production cycle

Geology & Deposits – defining the aspects

Exploration – looking for new resources

Resources – defining deposits

Mining – producing ores

Milling (Processing) – processing ores to a final product (usually yellow cake)

Closedown and Remediation after M&M – final steps after production

Environmental Issues – an integral part of the entire cycle

Converters

There are around 7 countries active in this market, with France, Russia, Canada and the US sharing almost 90% of the world's capacity.

The world capacity for conversion is currently nearly twice the amount needed to convert the freshly mined material, though some capacity is used for recycled materials

Enrichers

The majority of enrichment is carried out in the major nuclear nations, with Russia, France, the USA and the three Urenco nations (Germany, UK and the Netherlands) having around 95% of the world's capability.

Much of the Russian capability is associated with recycled materials and there is believed to be sufficient capacity available to meet projected needs for the next decade.

Commodity product

The end product of these processes is generally low enriched UF_6 (HEX) which is suitable for fuel fabrication and is treated as a commodity in the market place. Natural enrichment product is also available.

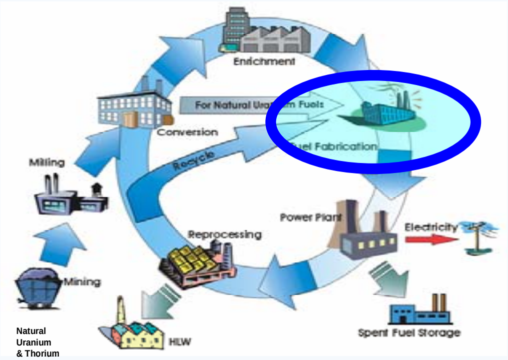
The next step in the process is to turn HEX into UO_2, and this powder product is also seen as a commodity product.

Commercial “product”

Finished fuel assemblies

Core components

Control assemblies



These items are available on the market but are specific to a particular power plant or operational strategy. Manufacture is highly specialised and subject to intellectual property rights (IPR) concerns.

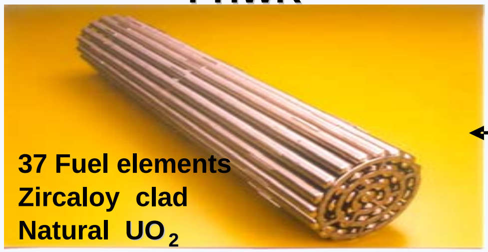
Power plant types

PHWR	– Natural uranium fuel, SEU
BWR	– <5% Enrichment
PWR (also WWER)	– <5% Enrichment

Advanced types: Pebble bed
Floating reactor
Gen IV
INPRO

Fuel types

PHWR

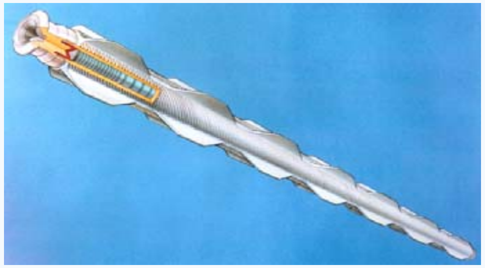


UO_2 or (U, Pu)O_2 Fuel Pellets

LMFR

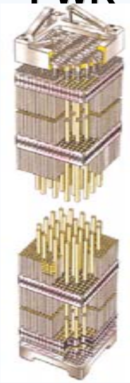
SS clad
(U,Pu)O_2

MAGNOX



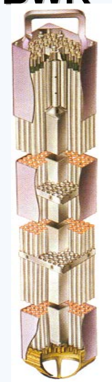
Magnesium Alloy Clad
Natural Uranium Metal Pin

PWR



17x17 Fuel Elements

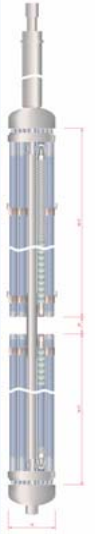
BWR



9x9 Fuel Elements

Zircaloy clad
Enriched UO_2
(<5%U -235)

RBMK



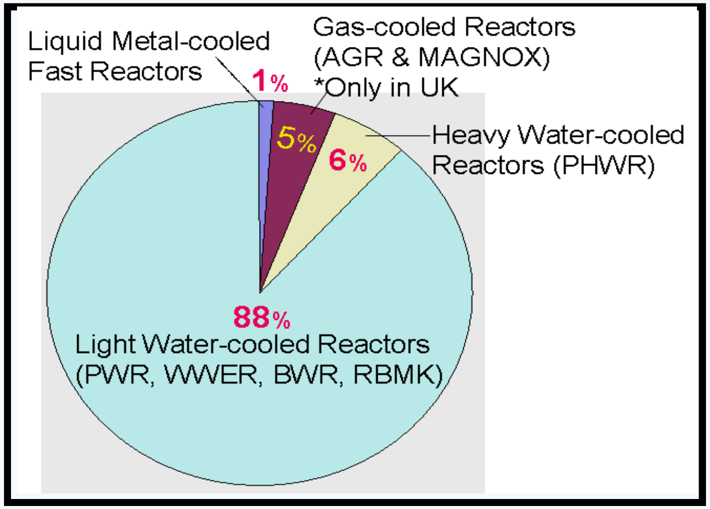
VVER

312 Fuel Elements

Zr-1%Nb clad
(<5%U -235)UO_2

AGR

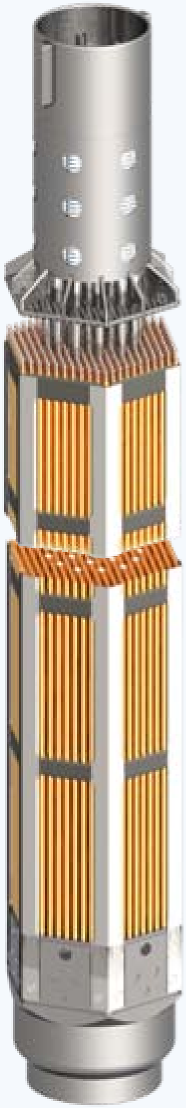
SS Clad
Enriched UO_2
(<5%U -235)



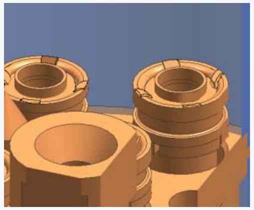
Water cooled nuclear power reactors are most common in the world today. Except for the Magnox reactors, all current NPPs use uranium dioxide or mixed uranium/plutonium dioxide (MOX) pellets as fuel

Fuel Bundle & Fuel Assembly

WWER-1000 Fuel Assembly TVS-A

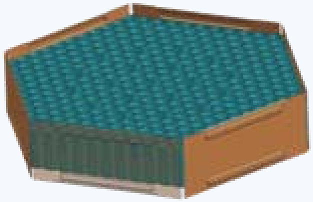


- 6 angles
- 8 spacer grids
- enrichment – up to 4.95%
- collet fixing of top nozzle
- temperature monitoring pipes
- collet fixing of fuel rod
- anti-vibration grid
- debris filter
- mixing SG
- decreased hydraulic resistance
- increased operational reliability

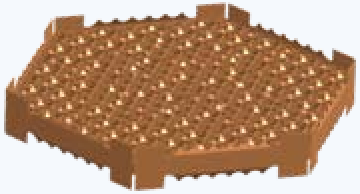


Elements for mounting top nozzle on GCs

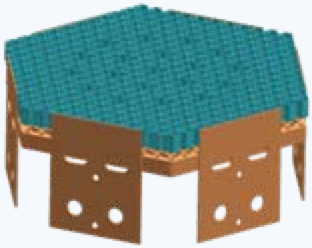
Top nozzle with improved temperature monitoring



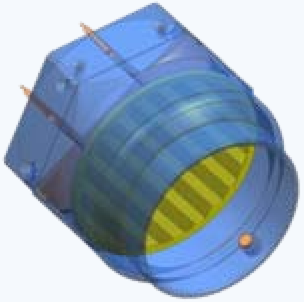
SG with arch-form cells



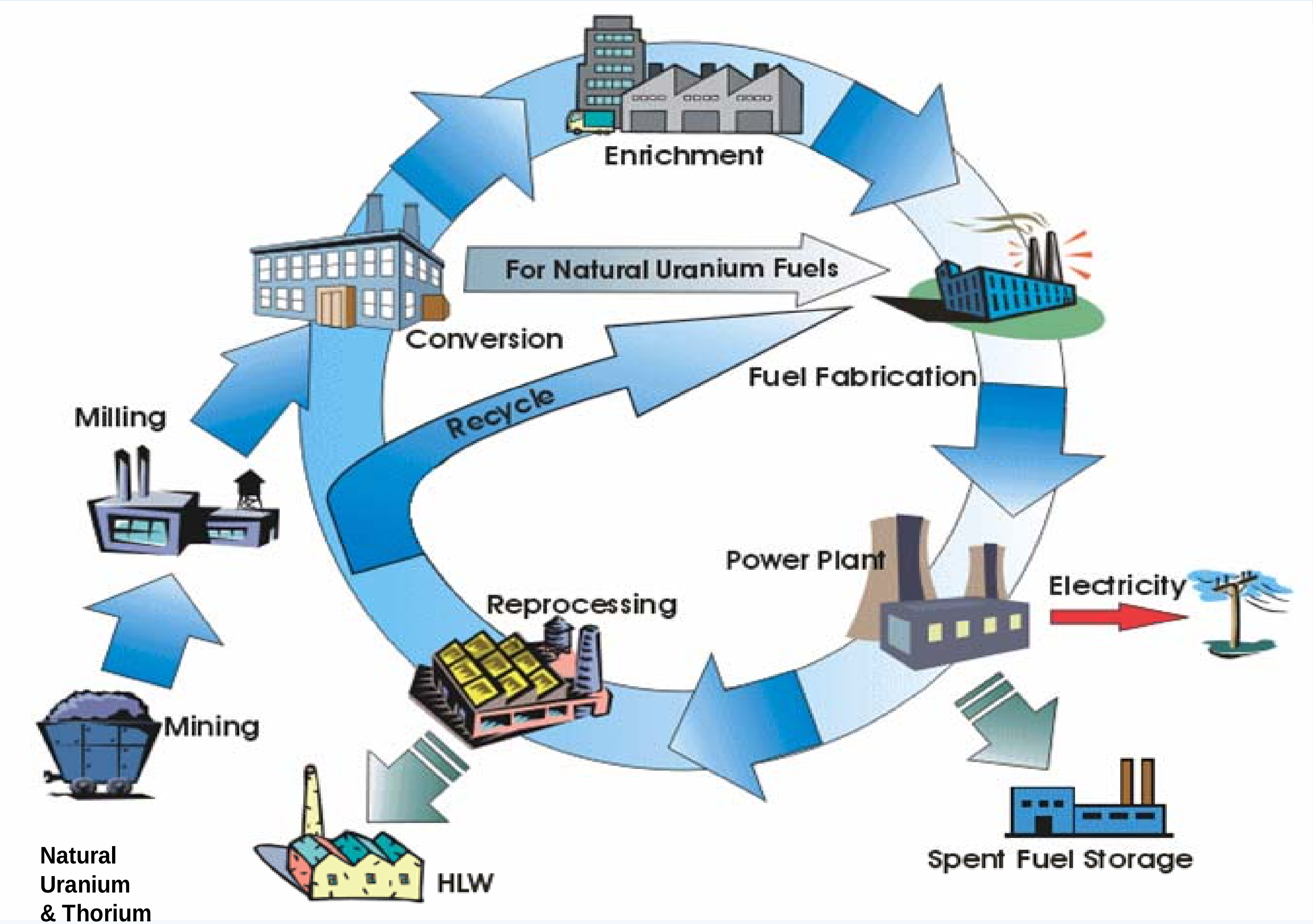
Mixing SG



Anti-vibration grid

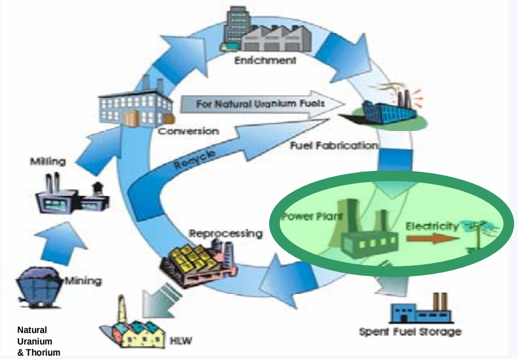


Bottom nozzle with debris filter


Enrichment
For Natural Uranium Fuels
Conversion
Fuel Fabrication
Recycle
Milling
Power Plant
Electricity
Reprocessing
Mining
HLW
Spent Fuel Storage
Natural
Uranium
& Thorium

Models of introduction of fuel cycle

Owner/operator - A simple turnkey model



Licensed by national regulator

Buys plant from turnkey vendor

Buys fuel services from vendor

Returns spent fuel to vendor

Accepts liability for waste arisings

Sells electricity

Models of introduction of fuel cycle - options

Owner/operator:

Buys plant from turnkey vendor

- Can require technology transfer
- Can require local content
- Can compete in specialist areas

Can act as Architect Engineer

Models of introduction of fuel cycle - options

Owner/operator:

Buys fuel services from vendor

- Can purchase from NPP vendor under lifetime contract
- Can require technology transfer
- Can purchase on open market – can be limited choice
- Can purchase commodity items and manufacture fuel
- Can have indigenous resources
- Can manufacture commodity items – e.g. conversion or enrichment
- Can manufacture speciality items, e.g. zirconium products

Fuel hardware and software (licensing) have similar ranges of options

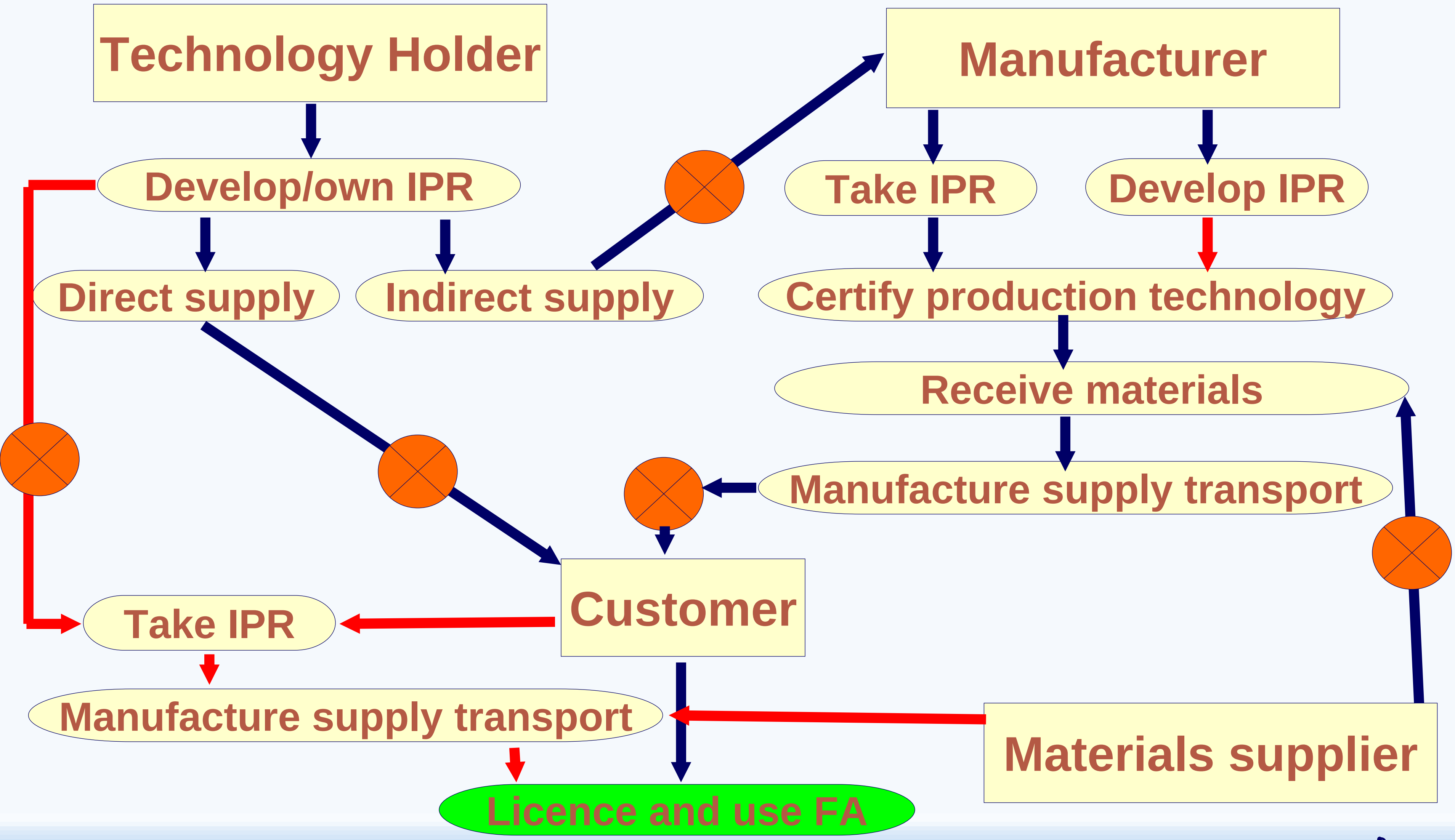
Security of Supply

Security of Supply: Fuel Assembly/Bundle Supply!

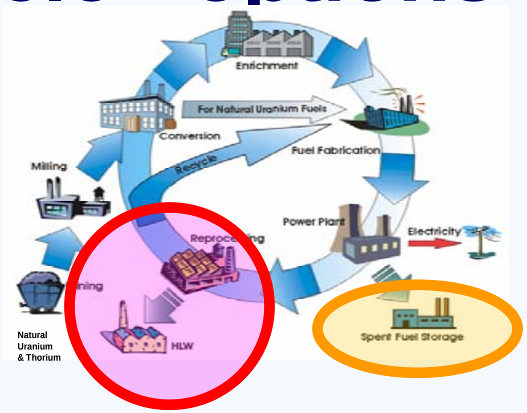
The Commercial commodities are available from a wide rage of suppliers and from many countries with widely differing political stances.

Fuel Assemblies are not so simple!

Chart of Fuel Assembly Supply



Models of introduction of fuel cycle - options



Owner/operator:

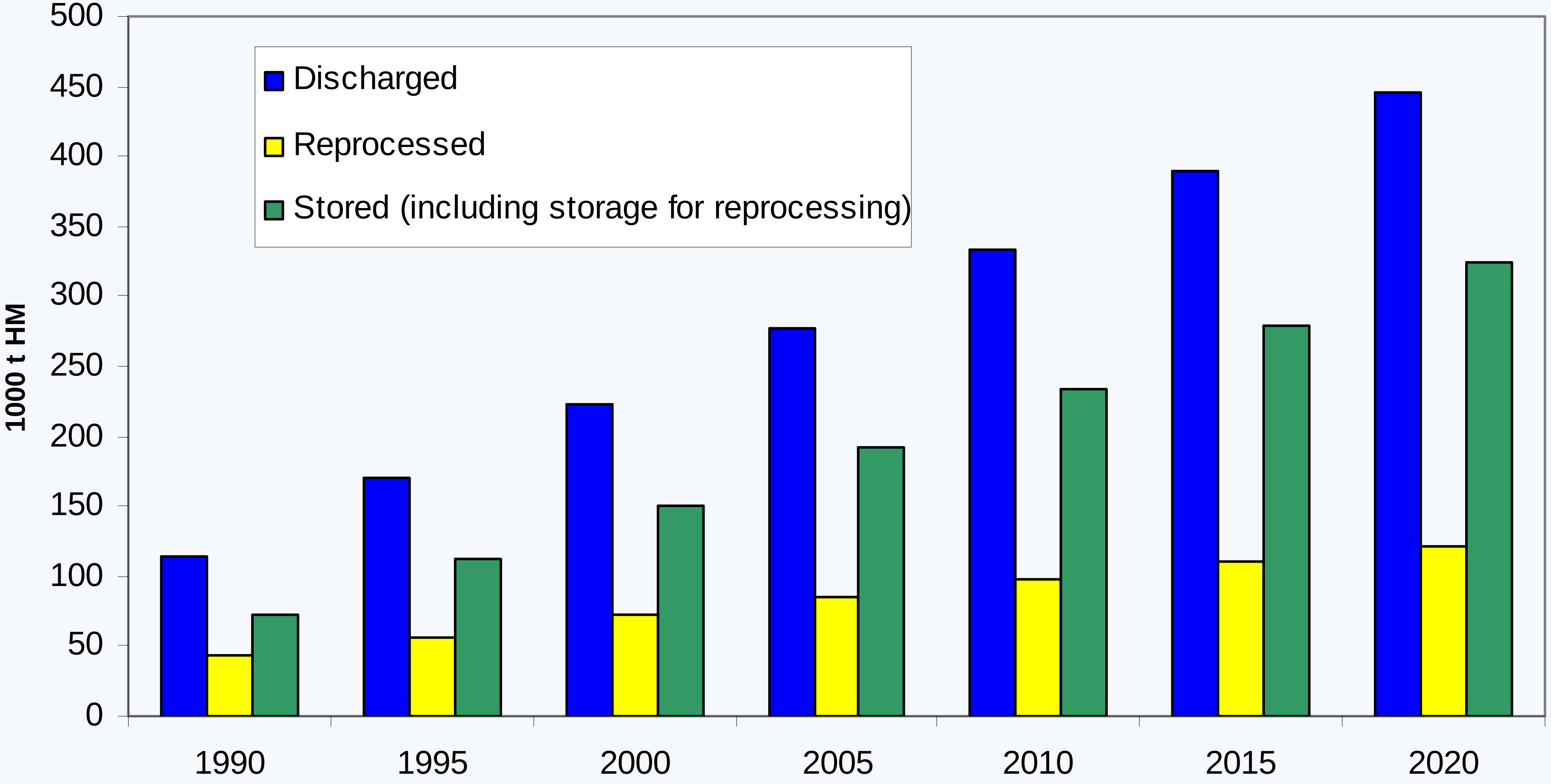
Returns spent fuel to vendor

- Can store fuel
- Can put spent fuel to long term disposal
- Reprocess

Issues include:

- Transport
- Licensing
- Public acceptability
- Security
- Returned High Level Waste from vendor

Spent fuel management



Spent Fuel Management Strategy

Uranium/Plutonium Fuel Cycle:

- Reprocessing for fabrication of MOX fuel and RU to be recycled
  - Currently limited
- Storage for 30-50 years and subsequent disposal as High Level Waste (The Once-through cycle)
  - Spent fuel disposal delayed due to mainly public acceptance problems.
- Deferral of the decision
  - The increased importance of long term (interim) spent fuel storage is being recognized. Storage can be at the plant or at a specialised central storage facility.

About Spent Fuel Reprocessing

- Reprocessing of spent fuel by PUREX process is a mature technology
- A number of options for spent fuel recycling are being investigated
- Issues like proliferation resistance, safety, radioactive waste management, and public acceptance are key factors in evaluation of its application
- Economy and Transport are also factors

Future of Reprocessing

- A number of options exist for recycling of spent fuel
- Some options like the ones that avoid separation of U and Pu are at advanced level of technical maturity
- Next generation of reprocessing plants are likely to be based on aqueous extraction processes, applying partitioning and recycling of fissionable materials to advanced LWR or fast reactors (FR)

Issues Related to Long Term Storage of Nuclear Fuel

- Mature storage technologies available commercially.
- Dry storage technology is increasingly being viewed as advantageous for long term storage.
- Improvement of storage technologies and their safety is continuing (i.e. Burnup credit and criticality safety).

Possible SFM Strategy for New Users of Nuclear Energy

- New countries considering application of nuclear energy are likely to adopt “wait and see” approach in spent fuel management.
- Development of regulatory capabilities and infrastructure for NPPs and for spent fuel management are prerequisites for new users of nuclear energy.
- New users need to be aware that introducing NPPs and associated SFM involves a commitment of at least 100 years.

Summary: Front End Fuel Cycle Policy

- Type of fuel
  - Fuel assembly/bundle with enriched fuel: light-water coolant;
  - Fuel bundle with natural uranium: heavy-water coolant;
  - Others
- Imported or domestic fuel supply
  - Transfer of fuel fabrication technology
  - Size of NPP program is an important consideration;
- Supply of uranium and enrichment service
  - Mechanism for assurance of supply: market competition or others
- Include transport

Summary: Back End Fuel Cycle Strategy

- Management of spent fuel:
  - ➢ Reprocessing for fabrication of MOX fuel and RU to be recycled;
  - ➢ Storage for 30-50 years and subsequent disposal as High Level Waste (The Once-through cycle);
  - ➢ Deferral of the decision.

Thank you