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Nuclear energy and the risks associated with resulting nuclear material

Scope of analysis

- Nuclear materials and waste:

  Limited to the waste from civilian use of nuclear energy
  i.e. neither waste arising from military purposes or industrial and medical uses

  Centered on the most active waste and/or those with the longest period
  - most directly linked to nuclear electricity generation
  - key issue in the decision on waste management

- A global risk analysis rather than a technical view on safety:

  From an approach centered on safety to a more global risk management

  From a site or material centered approach to a more "holistic" approach
  IAEA, *Nuclear Safety Review for the Year 2005*
  (…) to consider the holistic view of waste management and disposal
  that takes into account all factors and considers the entire life cycle

Safe management of radioactive waste

- A general principle for the international community

Rio Declaration 1992 / Agenda 21, Chapter 22:

Reaffirms the paramount importance of the safe and environmentally sound management of radioactive waste

IAEA Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management:

Objectives (Art. 1):

(i) to achieve and maintain a high level of safety worldwide in spent fuel and radioactive waste management (…)

(ii) to ensure that during all stages of spent fuel and radioactive waste management there are effective defenses against potential hazards (…), now and in the future (…)

(iii) to prevent accidents with radiological consequences and to mitigate their consequences (…)

From principle to practices

- Diverse and incomplete implementation:

A production linked to the choice of using nuclear energy:
While some countries have chosen to use nuclear energy, producing nuclear waste, some others regard the issue of safe management of nuclear waste as one reason for not using nuclear energy

From dilution to concentration:
"Prefered" solution went from sea dumping to geological disposal

Direct management or separation and conditioning:
Some countries regard direct disposal as the safest option, others have chosen to reprocess spent nuclear fuel

An issue that remains unsolved:
Some countries are more advanced in the management of some waste categories or the choice for the management of high-level long-lived waste, but no country has implemented a solution for that caterogy of waste

A past road paved with accidents / serious incidents

From pratices to principles

- A very complex set of:

  - materials to manage,
  - risks associated,
  - periods of time to consider,
  - technical options, available or thinkable

- Discuss a global table of materials and risks

  - form categories,
  - from intrisic dangerosity to risk management,
  - the problem of indicators

- Identify in current national / international practices some explicit / implicit choices behind the technical options

  - nuclear generation,
  - reprocessing,
  - storage,
  - final disposal

Radioactive materials and radioactive waste

- A whole range of radioactive, chemical, physical properties
- Five types of elements / use of nuclear fuel in reactors:
  - Uranium (U): the original ressource for use as nuclear fuel
  - Plutonium (Pu): from irradiation of uranium in the nuclear core
  - Minor actinides: from irradiation of uranium and plutonium in the reactor core
  - Fission products: from fission of some isotopes of uranium and plutonium in the core
  - Activation products: from irradiation of inert material (equipments, etc.) by the above (to some extent, same radionuclides as fission products)
- Materials to consider: all products containing elements from the above categories that have no direct use
  - "ultimate" waste if no re-use is foreseen,
  - "re-usable" materials, or "provisional" waste, otherwise

Categories based on period and activity

- Groups by homogenous proprieties: more than 100 types (Fr)
  Need for a smaller set of large categories
- Difficult to establish, depends on national priorities:
  no international classification (IAEA project under discussion)
- Classification usually based on period and activity,
  in relation to operational criteria for safe management:

  - the time-scale of containment needed

    e.g. in France based on radioactive periods
    very short life ≤ 100 days / short life ≤ 30 years / long life

  - the degree of isolation needed

    e.g. in France based on activity (in Bq/kg)
    very low act. ≤ 10^2 / low act. ≤ 10^5 / medium act. ≤ 10^8 / high act.

Intrinsic dangerosity

- General indications on the potential danger of the materials
  taking into account safety, radioprotection, security

Type of materials	Radio-activity	Radio-toxicity	Chemical toxicity	Criticality	Malicious usability
Uranium (U)	● (green)	● (green)	●● (yellow)	●●● (orange)	●●● (orange)
Plutonium (Pu)	●● (yellow)	●●● (orange) ●●●● (red)	●● (yellow)	●●●● (red)	●●●● (red)
Minor actinides	● (green) ●●●● (red)	●● (yellow) ●●●● (red)	●● (yellow)	● (green) ●● (yellow)	●● (yellow)
Fission products	● (green) ●●●● (red)	● (green) ●●●● (red)	None ●●● (orange)	None	●● (yellow)

An indication of the level of danger is given by a value from zero (none) to four, with sometime a fork between two values given.
Radioactivity, radiotoxicity and chemical toxicity are compared for an equivalent mass.
For each type of materials and danger the value given is based on the mean radioisotopes involved (for instance radiotoxicity of U-236, criticality of neptunium, use of tritium in nuclear devices, etc.).

Source: *Dessus, Laponche, Marignac, 2005*

From danger to risk management

- **Risk** = the combination of an intrinsic dangerosity with a potential scenario of exposure to the danger
- **Safe management** = reducing the risk i.e. *both* the intrinsic dangerosity and the potential exposure
- Need to take into account:
  - normal operation (or routine):
    exposition to radioactivity (direct radiation + site discharges),
    —> to keep corresponding doses well below a regulatory limit
  - accidental situations (or hasard):
    both internal and external causes,
    —> to limit the probability of higher doses than in normal operation
  - malicious acts:
    actions to spread radioactive substances and risk of proliferation
    —> to guarantee against situations with consequences beyond those considered for accidents

The problem of quantifying the risk

- Multiple quantitative and qualitative factors, e.g.:

  - physical form (solid, liquid, powder…),
  - chemical stability,
  - thermal output

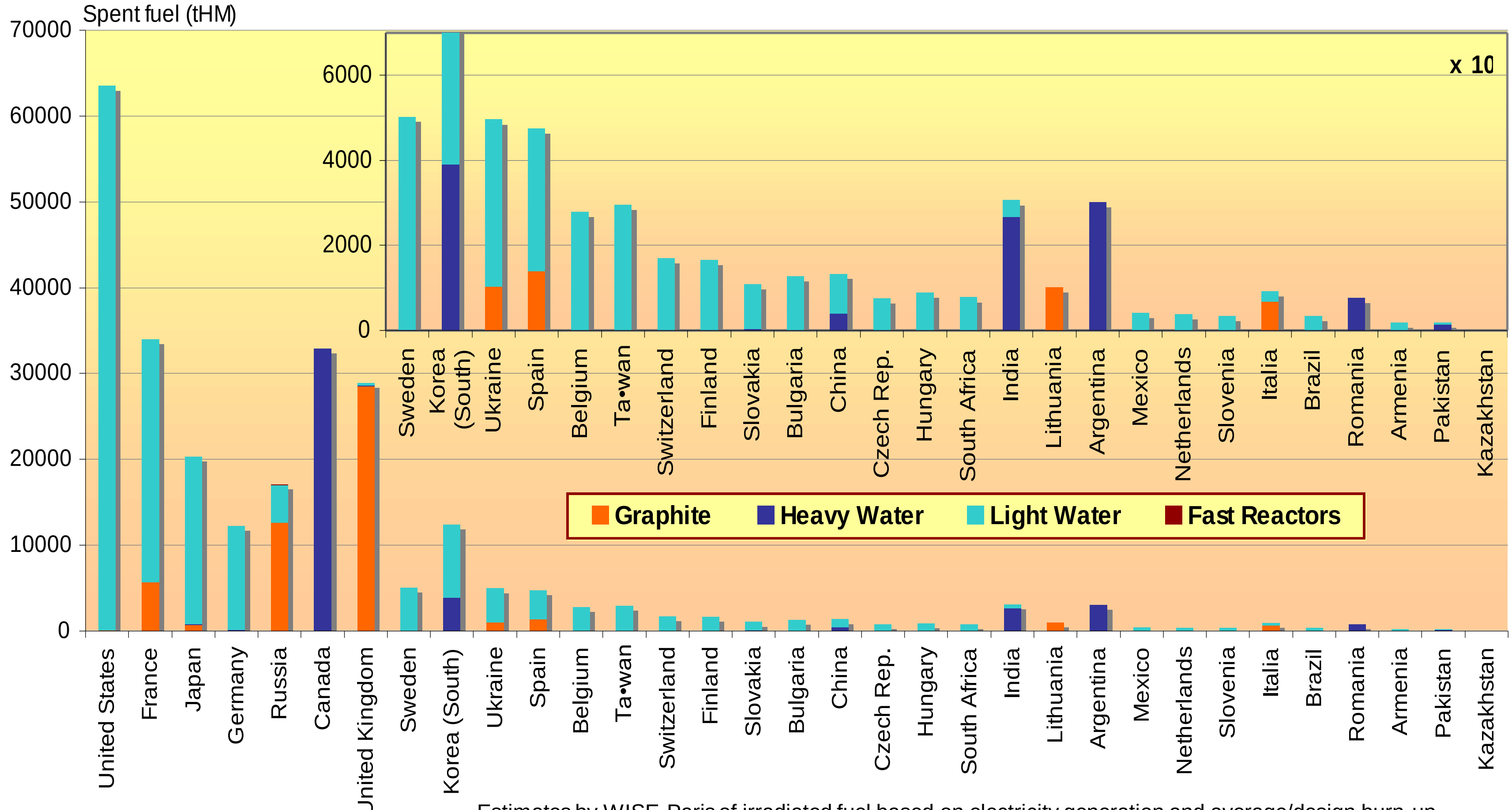
- Orders of magnitude can be found between categories of waste or in changes through time

- Usual indicators like volume, mass or radiotoxicity are too restrictive / must be used cautiously

- Quantification should not only be considered in terms of quantities stored / disposed of,
  i.e. the flows of materials and waste are important too

Cumulative irradiation of spent fuel

- Irradiated fuel from NPPs, by category (from start-up to 2005)



Estimates by WISE-Paris of irradiated fuel based on electricity generation and average/design burn-up.
Countries ranged bydecreasing total of electricity generation

Source: *IAEA, 2006 / CEA, 2005*

Quantitative and qualitative options

- Extreme variety of situations:

  33 countries out of 144 members of IAEA
  In European Union, 14 countries, of which 1 has stopped and 4 decided to stop

  Up to x 1000 factor in spent fuel quantities produced in those countries
  5 countries produce 66% of the spent fuel

- Quantities and type of spent fuel:

  More than 60% from Light water reactors, 0,1% from Fast reactors

  Quantities not proportional to energy produced (depend on enrichment, burn-up)

  18 countries only have one category to manage, in most others one dominant

- Raises different issues for spent fuel management:

  - volumes / activities

  - security and proliferation

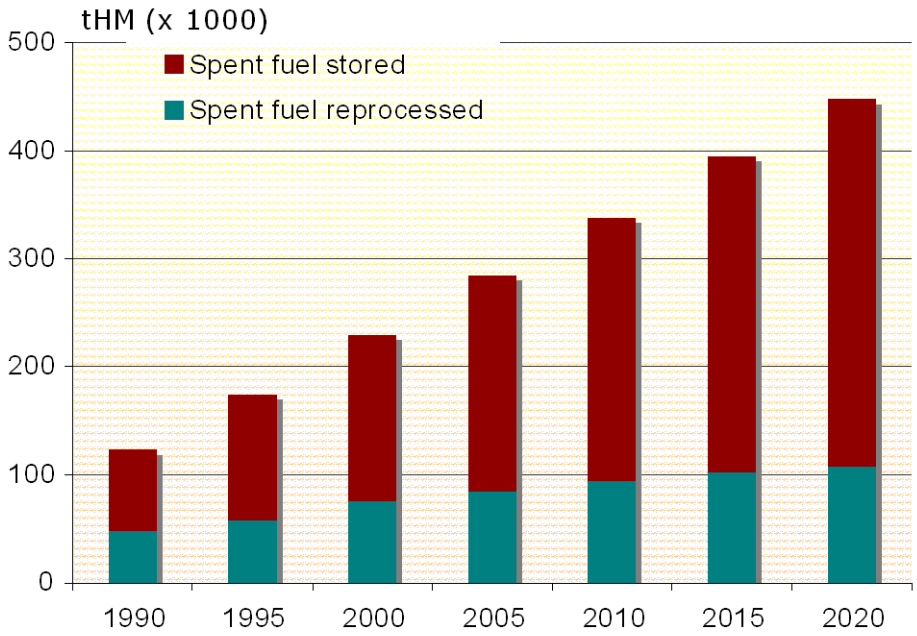
  - specific issues (e.g. graphite)

Reprocessing / Direct disposal

- A late justification of reprocessing: waste management

Only a few producers have chosen reprocessing and their number decreases
IAEA prevision: reprocessing gets minor (>40% of fuel up to 2005, <10% 2005-2020)

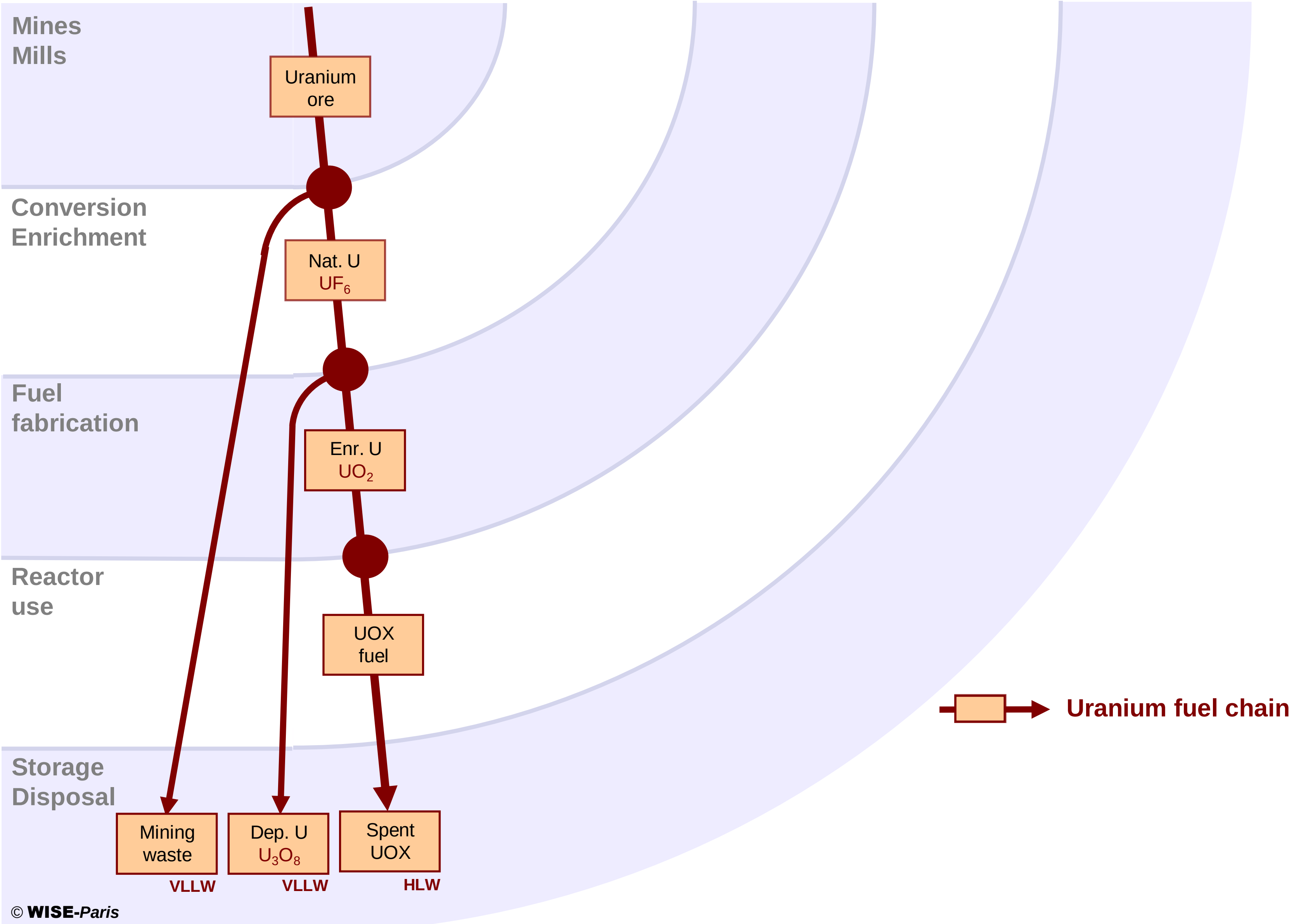
Spent fuel stored/reprocessed worldwide (cumul)



3 countries have developed reprocessing services for foreign clients
(France, UK, Russia)

Major clients phase-out reprocessing:
(Germany, Switzerland, Belgium)

Waste / material arising from the fuel chain



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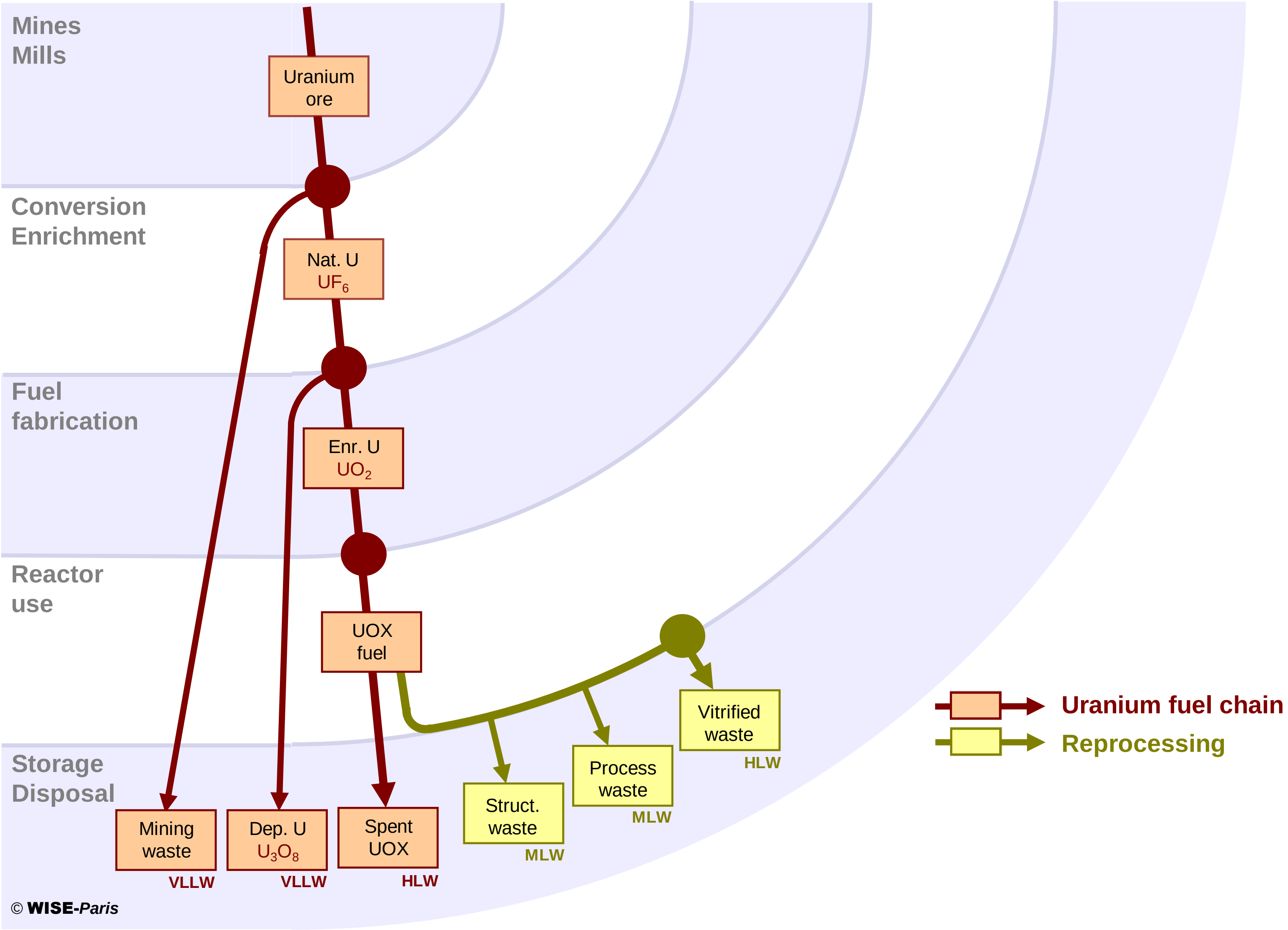

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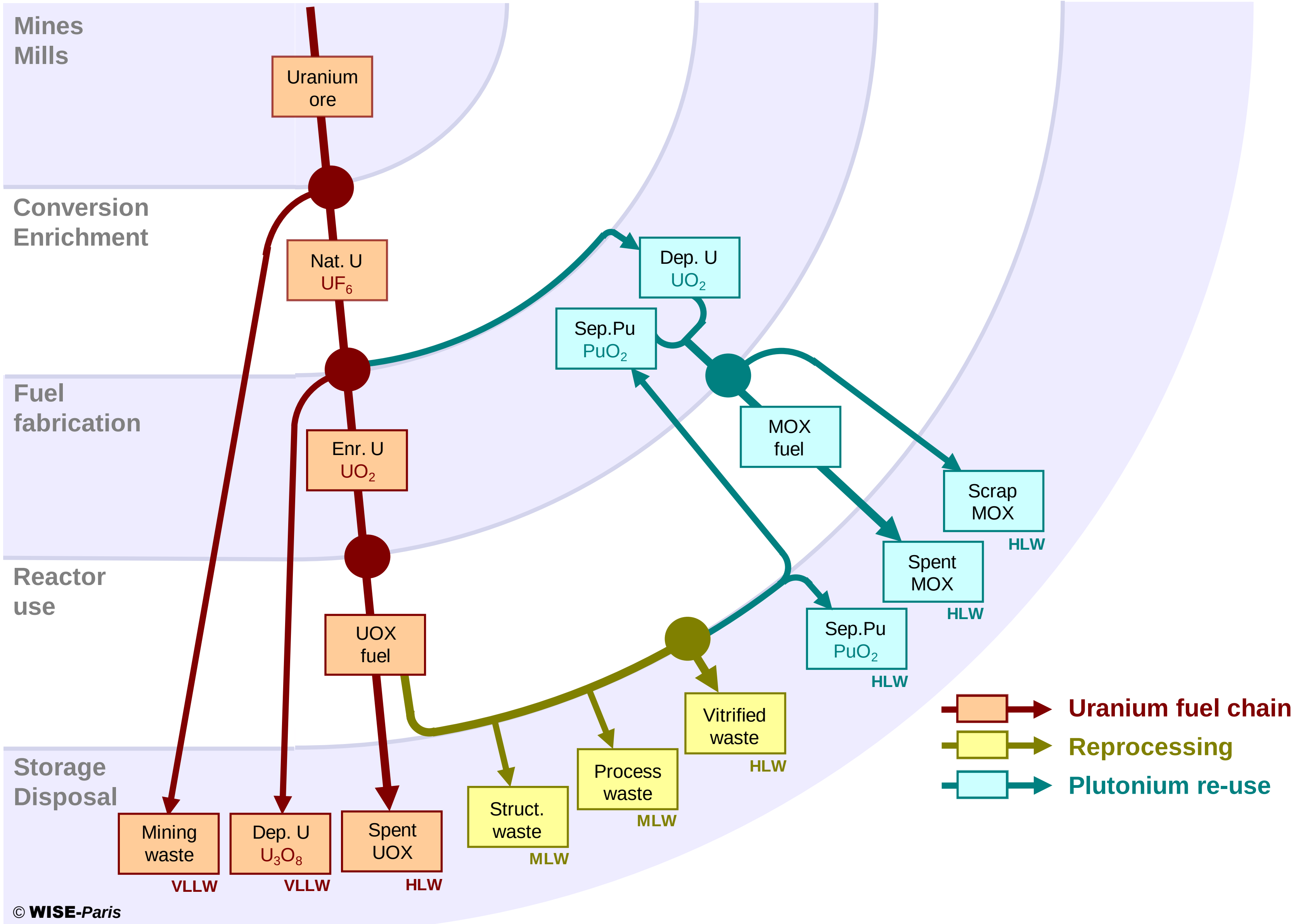

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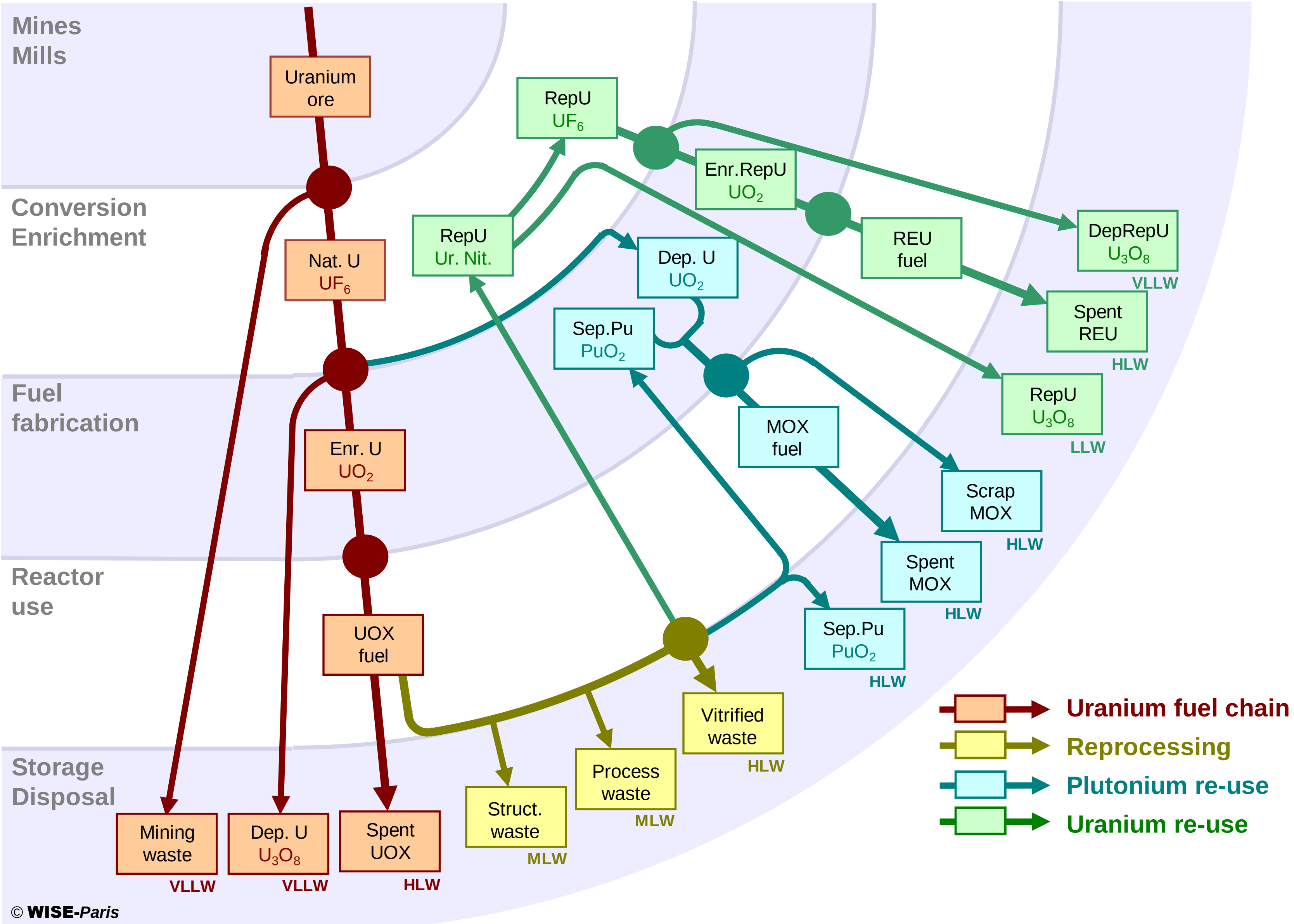

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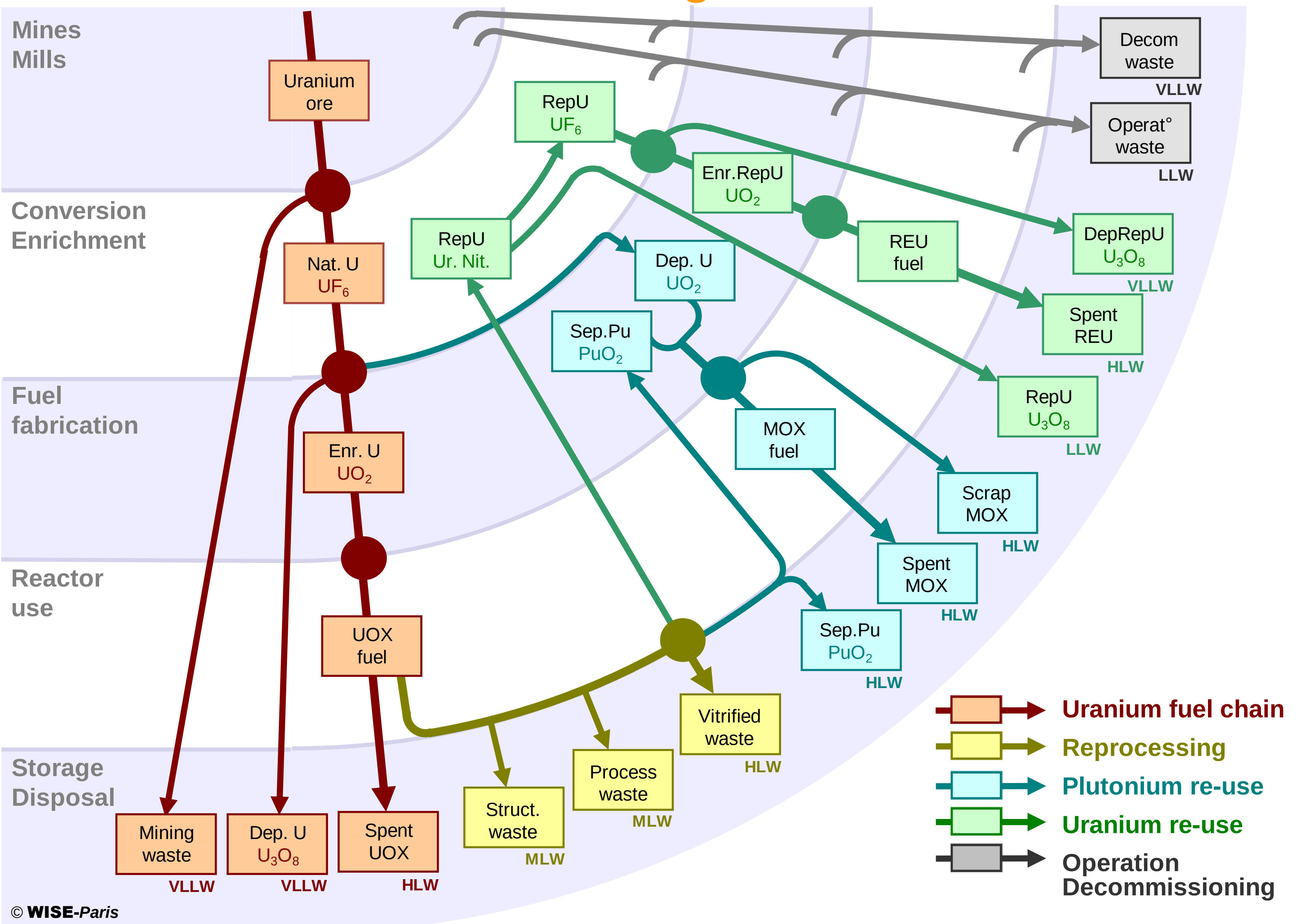

Implicit and explicit choices

- Inter-regional balance:

Foreign client countries received a waste inventory different from that sent
=> transfer of risk from one country to the other based (even if equivalence)

- Inter-generational balance:

Claim: reducing intrinsic radiotoxicity for future generations
Impact: increasing risks to present generation by both:

- increasing intrinsic dangerosity
  separating materials,
  concentrating storages
- increasing exposure scenarios
  more operations,
  more flows,
  more discharges
  (paradox in trends local/short term to global/long term impact)

- Inter-risks balance

Pre-empted options and foreseeable problems

- A much more complex management scheme:

  Claim: reduce quantitative burden for disposal
  Impact: increase qualitative problems
  - much more categories to consider
  - new risk management issues (e.g. spent MOX)

- Conditions of implementation:

  Observed: since implementation of the “recycling” strategy,
  the stocks of so-called re-usable materials increase
  - those considered for straight re-use (like plutonium)
  - those considered for “differed” re-use (like uranium or part of spent UOX)

  Plans about re-use involve new plants and implementation of new solutions

  Need for a global assessment of this strategy:
  - discussion of the feasability,
  - need to consider partial or total failure of the plan
    and discuss alternatives

Storage and disposal

- A wide range of solutions implemented for storage:
  - Spent fuel pools / dry storage
  Time period considered, thermal output and relation between burn-up and space
  - Centralized / decentralized in dedicated facilities or on-site at NPPs
  Burden between populations
  Vulnerability-sensibility of the system (transports, etc.)
  - Surface / sub-surface

- Decision in principle on geological disposal:
  discussed in most countries, made in a few, implemented in none
  Need for a prevision of inventory before making the safety case
  (qualitative and quantitative)
  Need of an agreement on the criteria for risk assessment:
  - time period to consider,
  - situations (normal, accidental, malicious) to consider in that time frame,
  - limits of potential impacts to demonstrate
  Issue of site location: local / regional / international share of burden

  Retrievability: indefinite "perenial" storage / reversible disposal

Partition and transmutation

- Very large uncertainty on the feasability:
  - Scientific experimental demonstration
  - Two qualitative and quantitative jumps needed:
    From a small sample in a reactor to a whole core
    From one reactor to a whole fleet of reactors maintaining required flows
  - No element of demonstration
- Same mechanisms of risk transfers than reprocessing but multiplied:
  - more operational and public exposure,
  - more safety problems,
  - more security concerns

Conclusions

- The use of nuclear energy produces nuclear material and waste that represent a **potential for danger**
- Choices made for the management of these radioactive material and waste imply decisions on:
  - the **balance** between different risks,
  - the **share of burden** / populations, territories, generations
- These balance and share have to be much better explicitly assessed than today
  if choices are to be based on a consistent basis
  and the corresponding risks clarified and accepted
- A general principle should be that, when possible, reducing the potential for danger is always preferred to transfer some risks