Karlsruher Institut für Technologie

World Transition Towards Sustainable Nuclear Fuel Cycle

IEMPT 11 (San Francisco, November 1st-5th 2010)

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FRAMEWORK AND OBJECTIVES

World energy demand will significantly grow in the mid term future. It is foreseen that the world nuclear energy production share could drastically increase within the next century.

Sustainable supply of these considerable energy needs by using only the thermal reactors is questionable due to a limited natural resource of uranium. Therefore the transition from present open or partly closed to a fully closed fast reactor fuel cycle, implementing P&T for waste management seems in middle and long term unavoidable.

Two transition scenarios towards sustainable fast reactor fuel cycle are investigated using both a homogeneous (i.e. no distinction among different regions in the world) and heterogeneous (i.e. the world subdivided in different regions with e.g. different energy demand growth) transition scenarios.

Scenario simulations were performed with COSI6 (ver. 5.1.3) code developed by CEA.

This work has been performed in the frame of the NEA/OECD Expert Group on Fuel Cycle Transition Scenarios Studies

This type of studies is very dependendent on hypotheses, in particular energy demand growth and resources availability.

In the present study it has been considered that a major parameter constraining the world transition scenario analysis is the available mass of natural uranium resources.

It could be argued that a better parameter would be uranium cost versus cumulative uranium production since today uranium cost is ~2-4% of the cost of electricity, even a very sharp increase of cost to a sharp increase on uranium requirements for new reactors, would not affect the nuclear electricity cost in a significant way.

However, cost considerations and projections over a period of a century can be rather dubious and one should pay more attention to practical and very important issues, as e.g. the pace of introduction of new mines in different regions in the world, with significant impact on the reliability of supply, that could modify and put in a very different perspective any hypothetical cost consideration.

World Scenario: Subdivision in 4 Regions

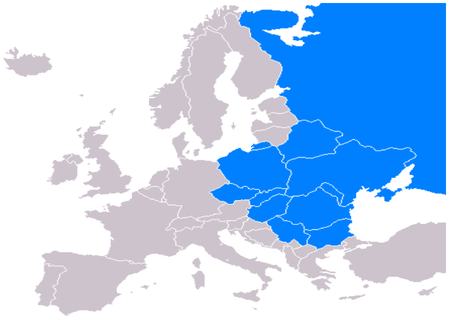
OECD90
Western Europe,
North America and Pacific

ALM
Middle East, Africa
and Latin America

Homogenized World

Asia
Centrally Planned
Economies of Asia, Southern Asia
and Pacific Asia

REF
Russia, Eastern Europe
and former Soviet Republics



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Main Hypotheses and Assumptions

- **Analysis period:** from 2010 to 2200
- **Fuel cooling times:** 2 and 5 years
- **World Reprocessing capacity:** fixed up 2030 to present values
- **FRs introduction date:** 2050 (*homogeneous option*)
- **Reactor type used for calculation:** SFR both with metal (breeder FRs) and oxide fuel (isogenerator FRs)
- **Breeding gain:** 0.47 (breeder FRs) and 0.022 (isogenerator FRs)
- **Composite Doubling Times (CDT) for breeder FRs:** 11.7 and 17.8 years
- **Present spent fuel inventory:**
  - LWR: 157,560 tonnes
  - MOX: 535 tonnes
  - FR: 56 tonnes

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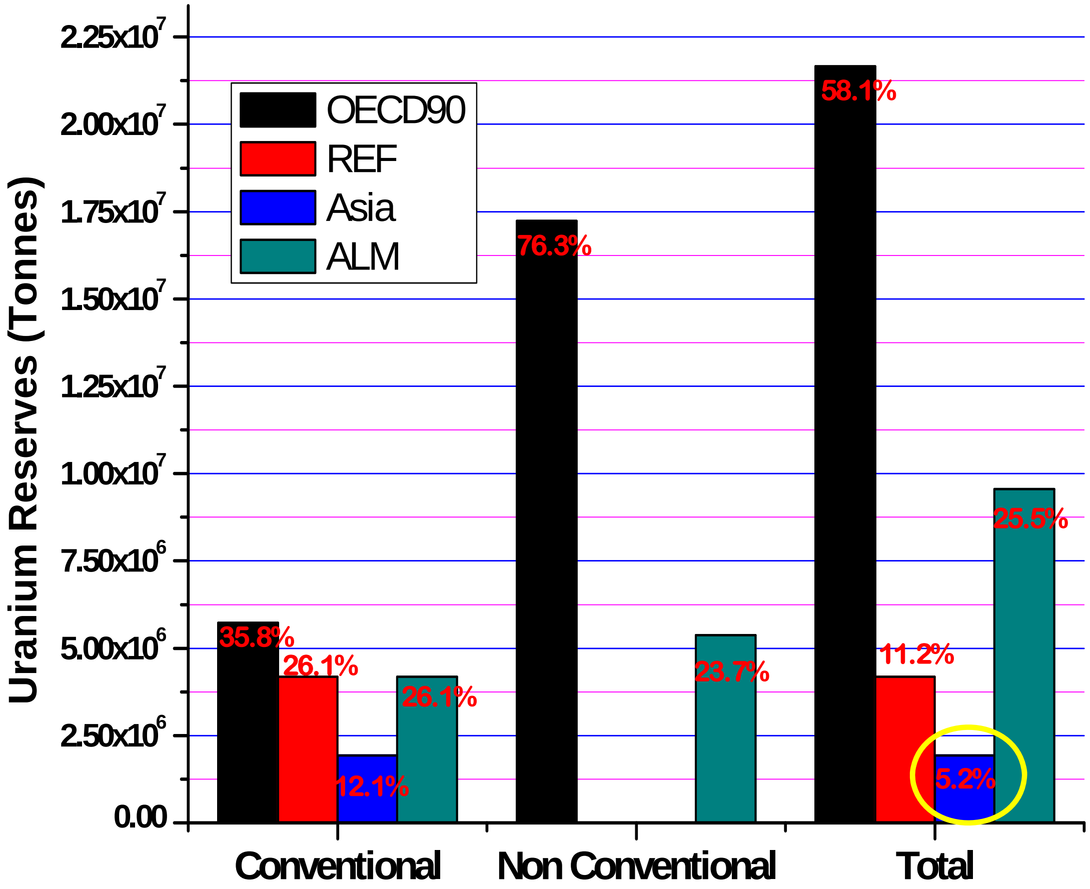
Uranium Resources Subdivision

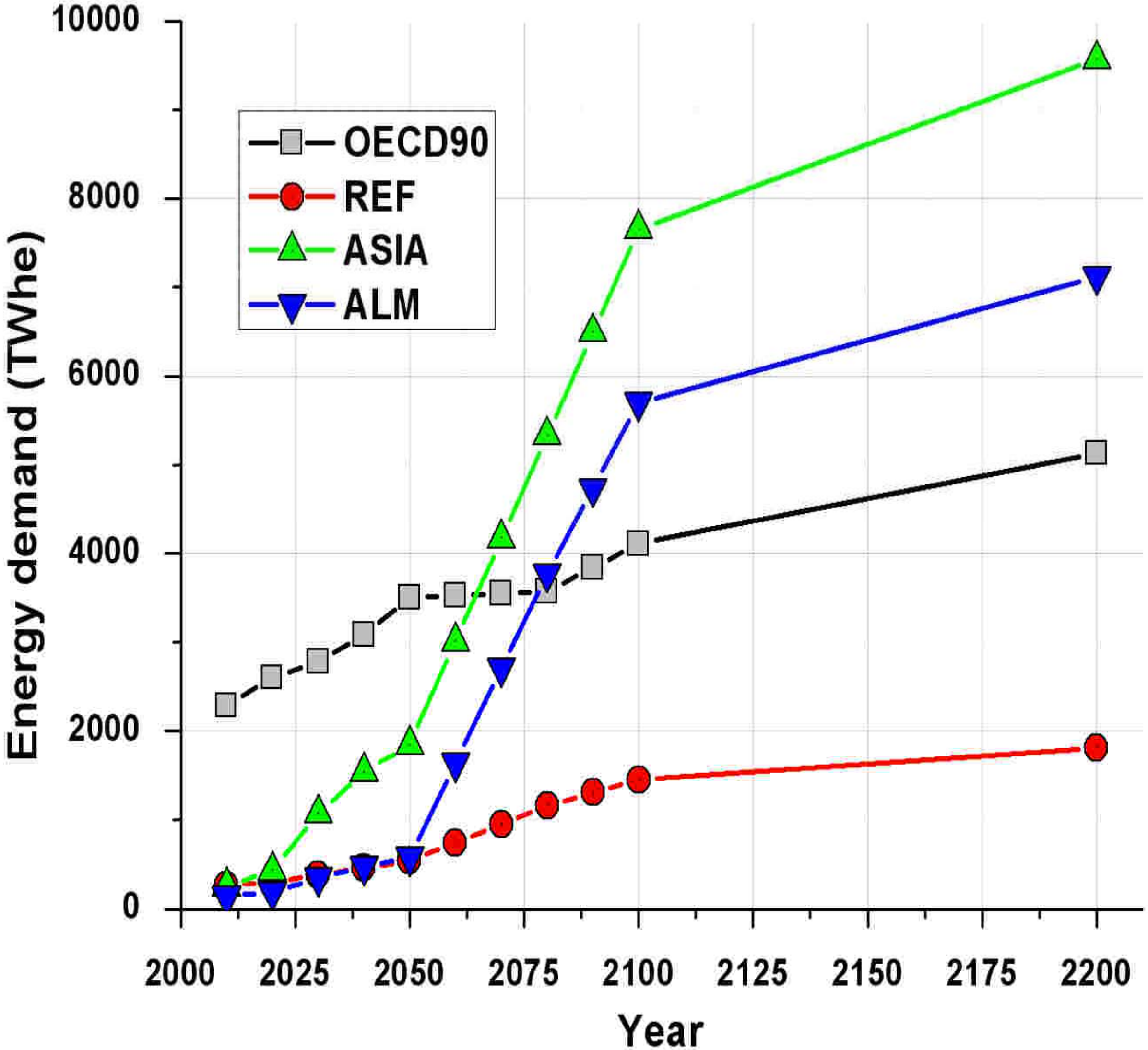


- **Uranium world reserve estimate: ~39 MT**

- **Conventional resources taken from NEA** ***Red Book 2007 (minor differences with Red Book 2009, which include higher price reserves)***

- **Unconventional resources taken from Oxford University Press 0961- 1444/94 (assumed equal to ~22 MT)**

Energy Demand



Total energy demand according to IPCC *(scenario B2-MiniCAM)*

Regional subdivision looks questionable (e.g.: both ALM and ASIA overtake OECD demand before 2035), so it was rescaled to the IIASA share *(Middle Course scenario B)*

Hypotheses and assumptions were discussed in OECD/NEA WPFC expert group

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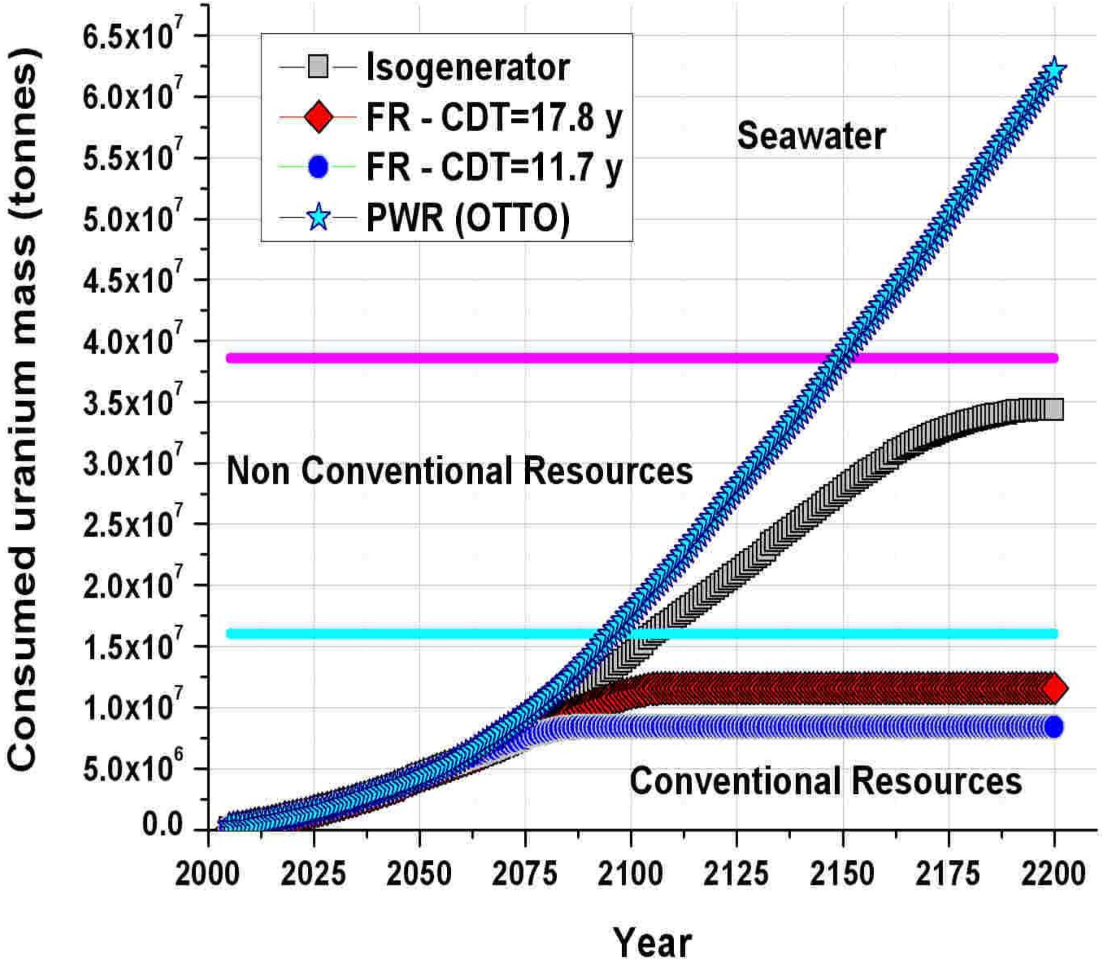
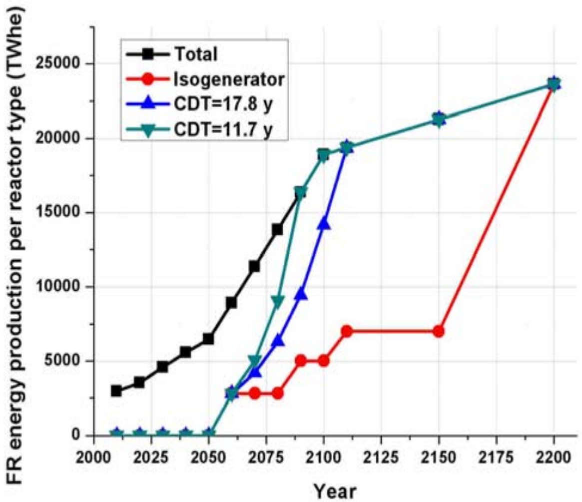
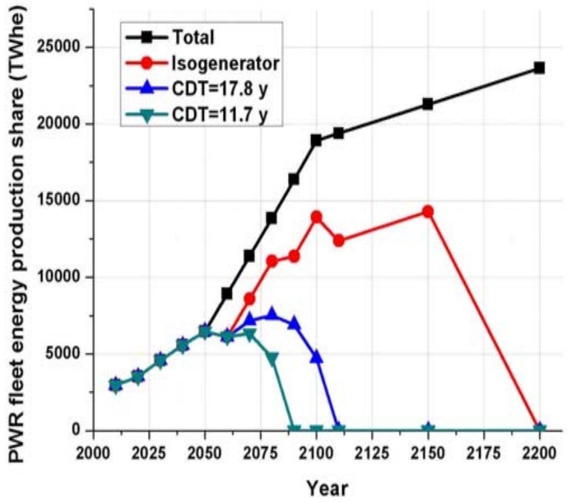
Homogeneous Approach: Main Results







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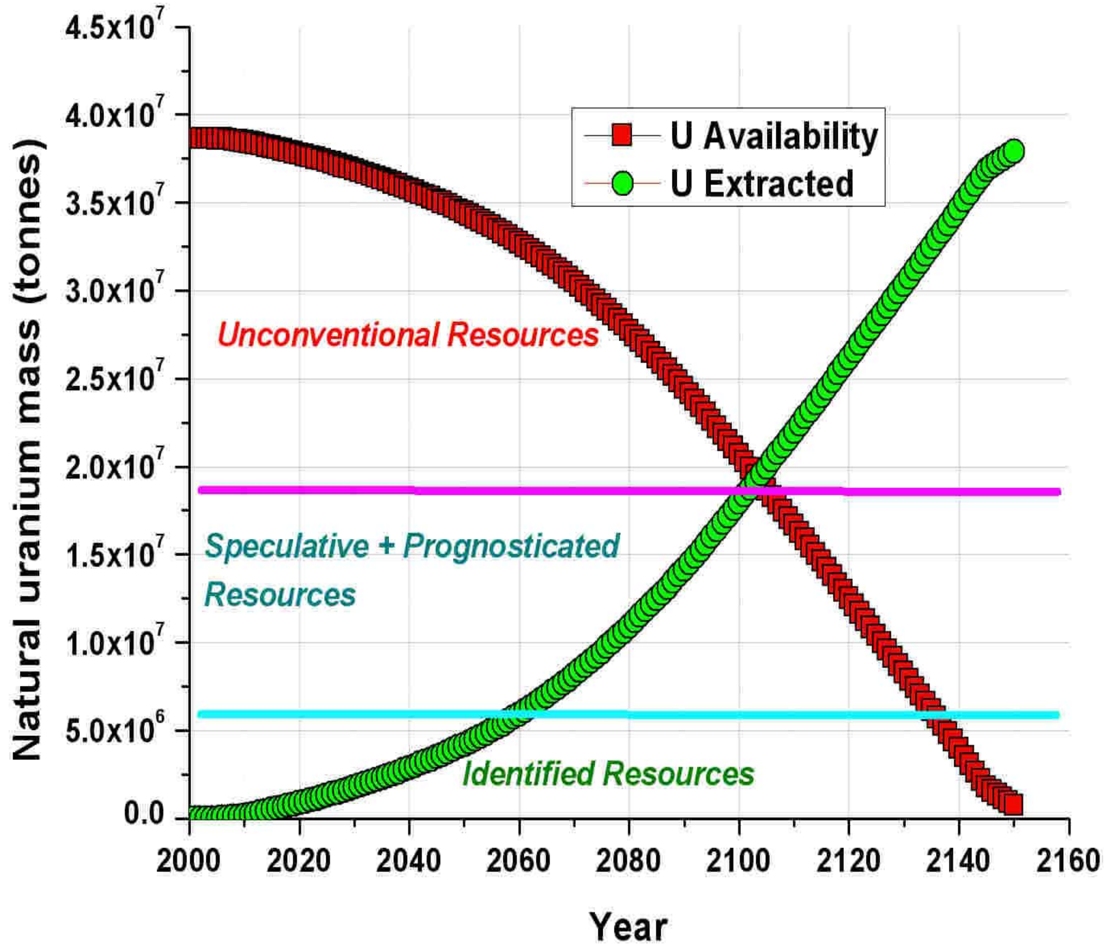
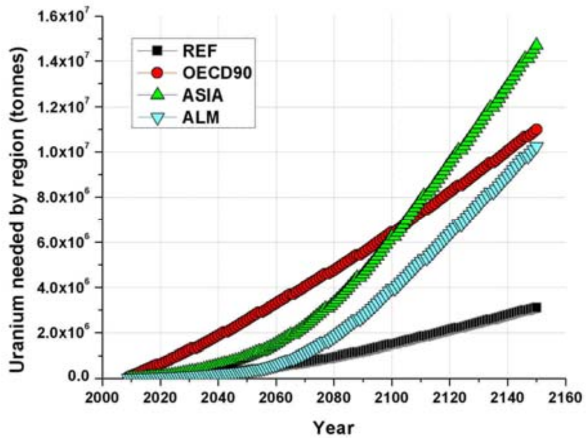
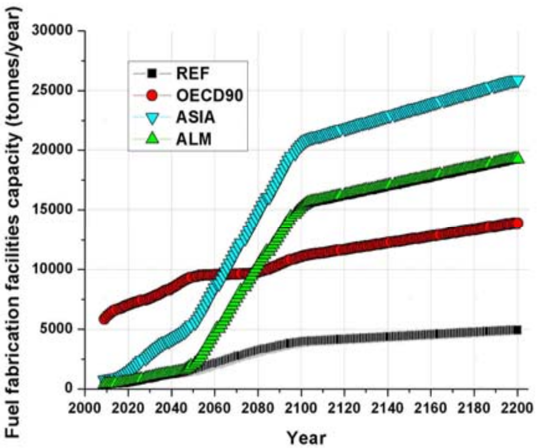
Impact on Resour. and Infr. (*Het. Option*)







The largest amount of resources will be required by ASIA, but it should be remembered it owns only ca. 5 % of the world reserves

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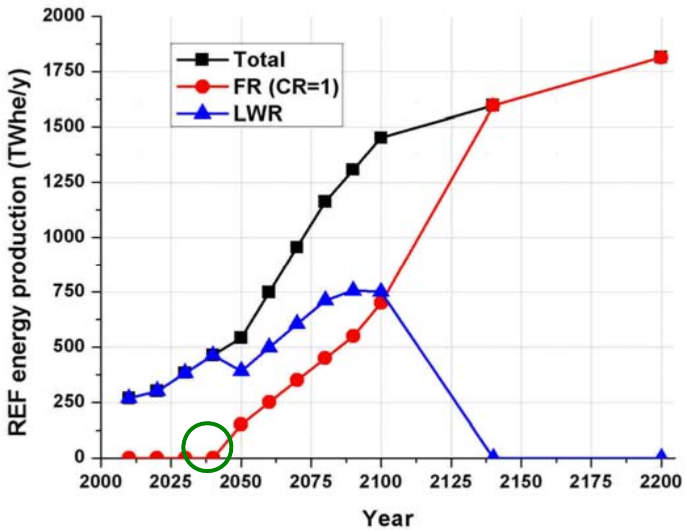
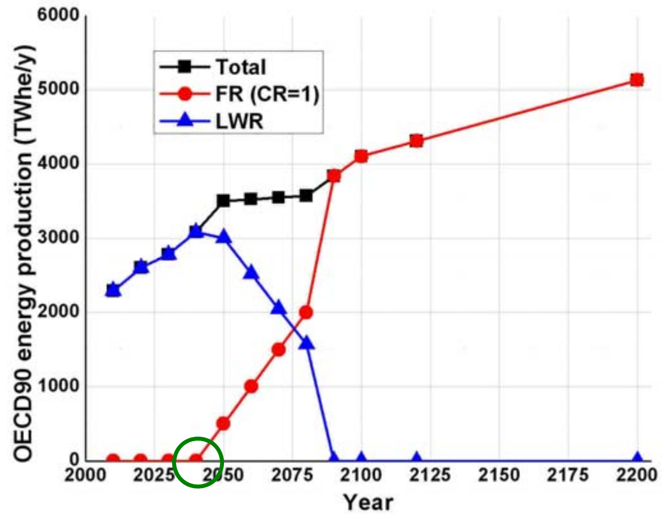
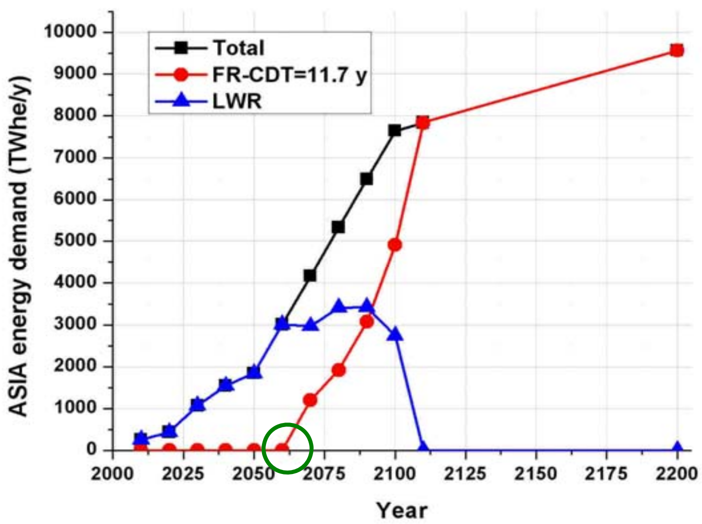
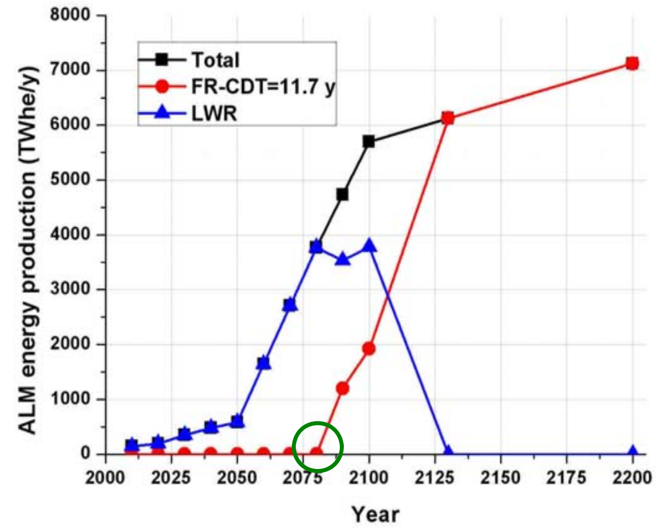
Heterogeneous Approach: Main Results









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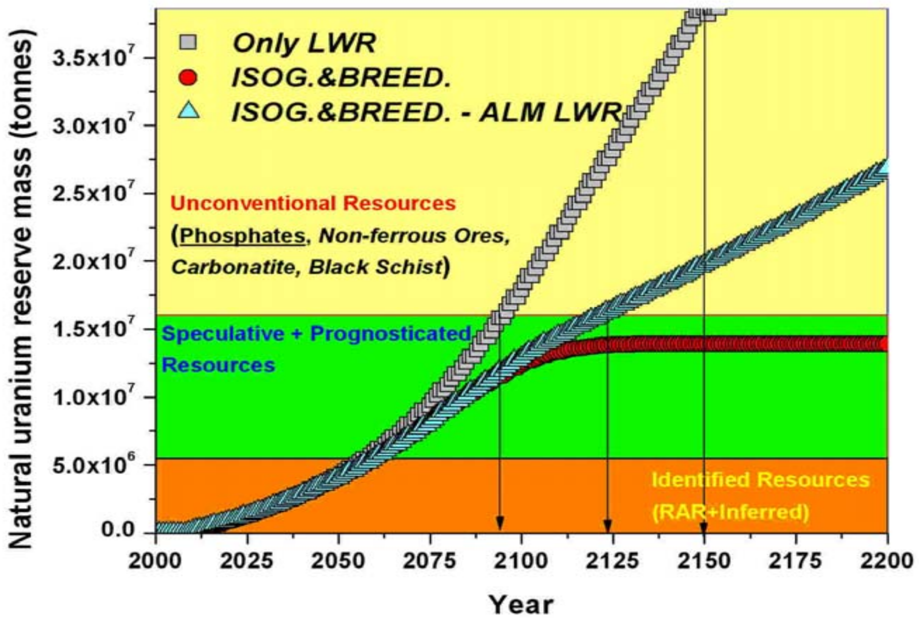
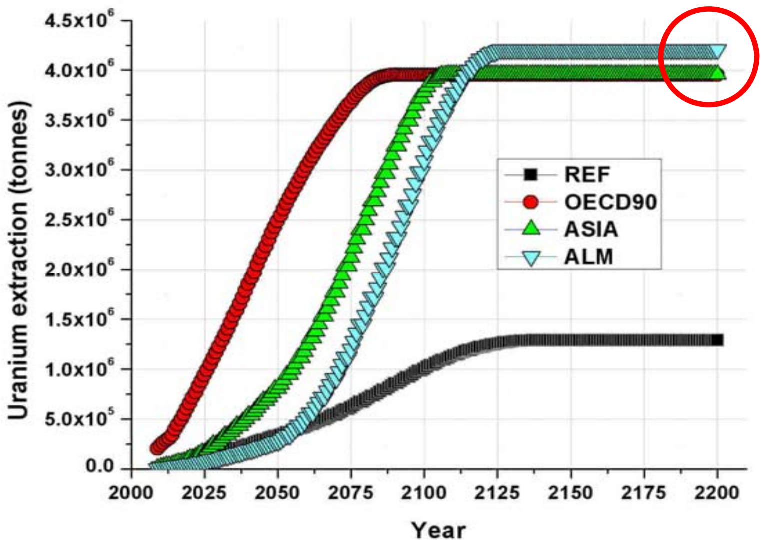
Impact on World Uranium Resources

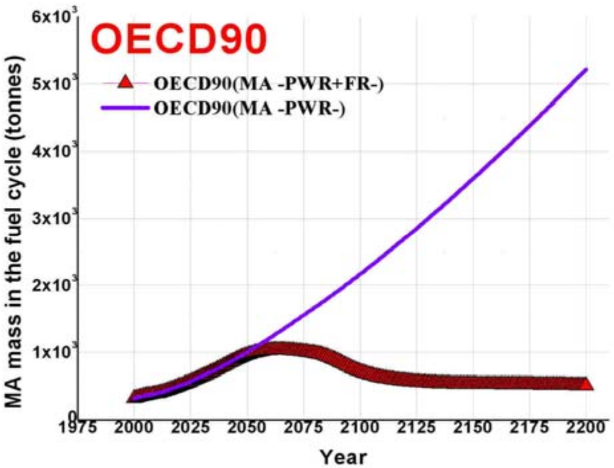


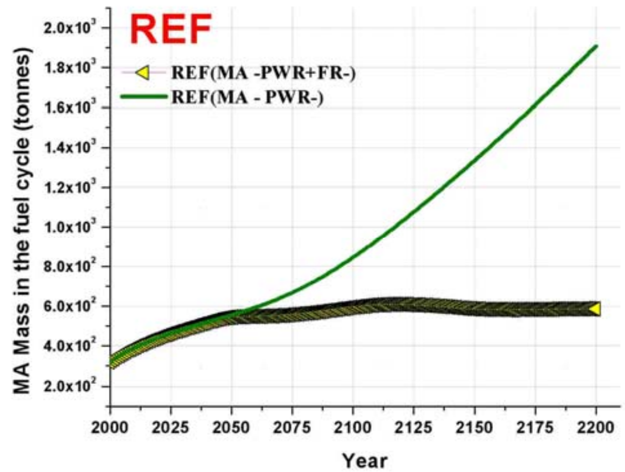


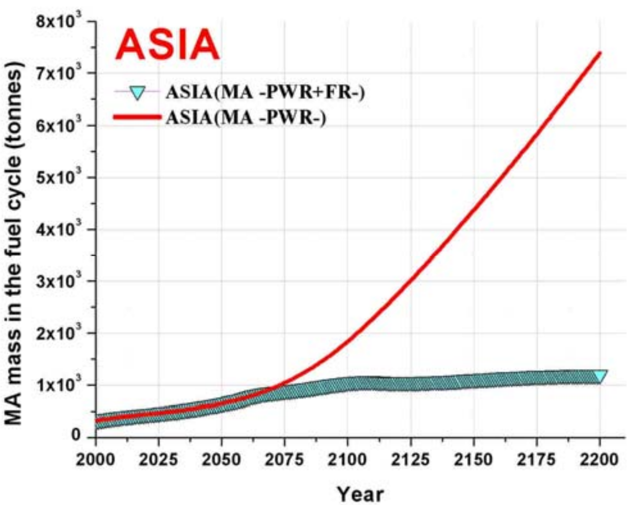
Following the hypotheses, in case of once-through LWR cycle unconventional resources limit is hit before the end of the century *(causing possible stress on U market)*, while this limit in never reached if FRs are adopted by all the macro-regions. In case ALM pursues only LWR OTTO cycle the limit is reached around 2125.

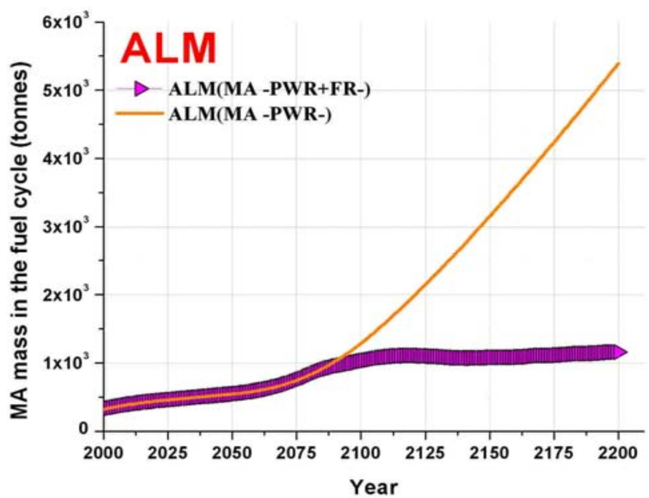
Due to a later FRs introduction ALM requires a larger amount of U resources, despite the lower energy demand

Minor Actinides Mass in Fuel Cycles









Big differences are observed between LWR open cycles and FRs closed cycles *(up to one order of magnitude)*

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Infrastructure Requirements

- **Fabrication capacities required:** ~ 10,000 tonnes/year by 2057 in ASIA and by 2070 in ALM

These numbers should be compared with present OECD fabrication capacity (~ 9,000 tonnes/year)

~ 11,000 tonnes/year by 2040 in OECD

- **Due to FRs introduction situation changes in the second half of the century due to FR fuel requirements:**

~ 5000 tonnes/year by 2080 in OECD

~ 18,000 tonnes/year by 2110 in ASIA

~ 14,000 tonnes/year by 2130 in ALM

- **Similar trends for reprocessing capacity requirements:**

With respect to present World UOX capacity (~ 3800 tonnes/year) a value 6-7 times higher should be needed in ASIA by 2100, 4-5 times in ALM

Growing rates of the order of 2500 tonnes/year in fuel reprocessing capacity should be required (i.e.: a La Hague size reprocessing plant every 7 years)

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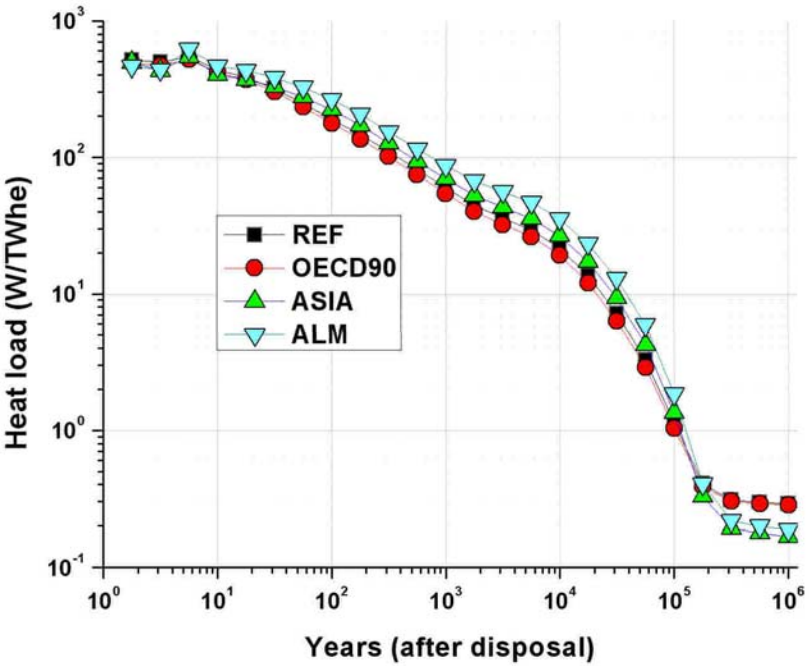
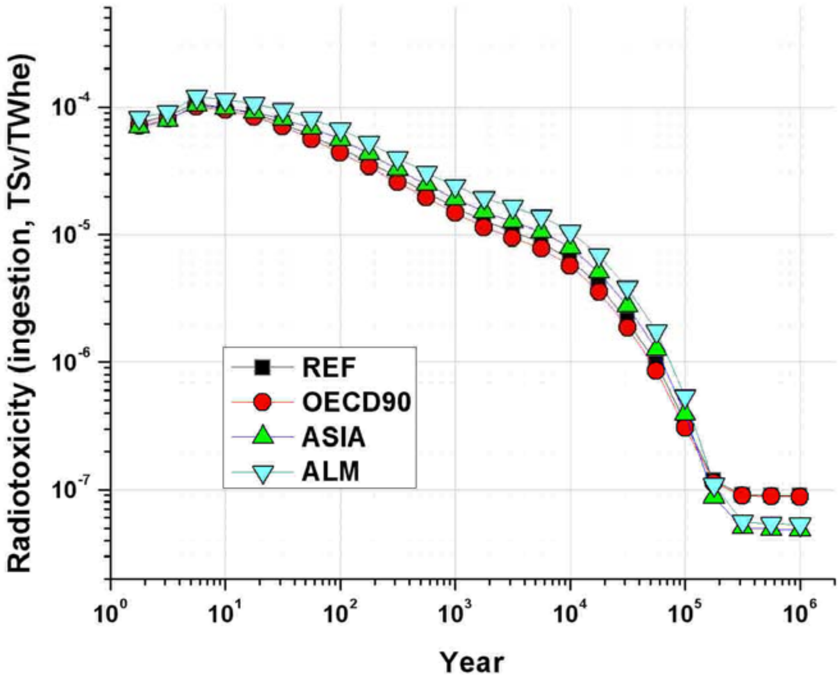
Specific Heat Load and Radiotoxicity





COSI6 scenario code allows also detailed evaluation of FC strategy impact on geological repository issues *(if required)*

In this case REF presents the higher values *(although differences are not sensible)* due to the late introduction of FRs

Conclusions (1)

- The present study obviously does not pretend to be exhaustive, but gives a first parametric view of a world scenario for the next decades

- Tools available at present, such as advanced fuel cycle simulation codes, should support this kind of investigations

- Hypotheses are very difficult to set up, and obviously present a strong impact on results

- Given some reasonable initial hypotheses it is however possible to evaluate the impact on U resources

- A stress on resources is possible before the end of the century if fast reactor technologies are not implemented, especially by the most fast growing economies macro-areas

- This should cause however a spectacular increase in dedicated infrastructures demand

Conclusions (2)

- It has been shown that the need and the deployment pace of fast reactors in the different world regions is determined:

- **by the hypothesis on the energy demand growth,**
- **plutonium availability,**
- **natural uranium consumption (which, in our study should not exceed a critical limit),**
- **fast reactor core conversion ratio,**
- **ex-core time of spent nuclear fuel,**
- **target burn-up of UOX fuel impacting the quality of plutonium vector,**
- **reprocessing and fabrication capacities available in the future.**

- Impact on high level waste inventory to be disposed of and fuel cycle metrics such as radiotoxicity and heat load per energy produced have also been preliminary assessed.

- Further investigations are needed in order to improve the results of the present study *(in particular parametric studies on the hypotheses, economic evaluations, proliferation considerations, etc.).*