Overview of the IAEA white paper « The Future Role of Water Cooled Reactors in the 21st Century »

Focus on technology development issues

« The Future Role of Water Cooled Reactors in the 21st Century » The need for new WCRs

- Drastic expansion of nuclear power demand is anticipated and WCRs are expected to play the main role continuously in electricity generation during the 21st century
  - To replace present operating NPPs
  - To provide the bulk of the additional nuclear power capacity

- WCR technology is the only realistic nuclear technology for most of the century
  - Substantial technology base exists, it gives confidence of safe, reliable and economic operation
  - Design evolution may provide a bridge towards more advanced technologies (i.e. Gen IV)

Status of the WCR Technology

- A mature technology
  - Allows to take benefit from the many reactor-years of experience and know-how technology accumulated worldwide
- But still a young technology
  - We are just building the third generation of such NPPs !
- Technology improvements should be considered for addressing/resolving the key technical issues identified that may preclude WCRs to achieve their future role
  - Suggestions for initiatives in the area of IAEA's water cooled reactor technology development sub-program for future projects and activities

The Key Technical Issues

- Main technical challenges
  - Cost optimization (investment, operation and maintenance)
  - Potential scarcity of fissile resource

- Other topics
  - Safety/Security
  - Wastes
  - Proliferation
  - Siting and grid

➔ Don’t forget that non-technical issues such as Political Consensus and Public Acceptance are also true key issues that may preclude the "Nuclear Renaissance"

Cost optimization

- Promote standardization to allow the deployment of new nuclear built at large scale
  - Standardization of customer requirements
    - e.g. load follow performances
  - Industrial codes and standards
  - Rationalization of licensing approaches and safety standards

The latest unit to be built should take advantage from he lessons learned in previous construction

- Robust designs are required
  - to provide margin in operation, maintenance, lifetime…
  - to address deployment in regions with high population density

Cost optimization
Prepare evolution of design

- Enhance core performance
  - High fuel burnup
  - Increase power density
- Design for a long economic lifetime and to avoid obsolescence
  - Equipment subject to wear should be designed for easy replacement of worn parts, other equipment can be designed for longer duty (lower stresses)
  - Support research program in improved materials more resistant to radiation damage, corrosion…
  - Flexibility in I&C
- Optimize the use of active and passive safety systems
  - Incorporate best features either active or passive to optimize cost while maintaining an outstanding safety level

Cost optimization
Prepare evolution of design

- Improved thermodynamic cycles
  - Development of turbine with enhanced performances
- Small and Medium size Reactors
  - Smaller, cheaper and simplified reactor designs would be nice
  - Will an innovative design of WCR be able to offset the price penalty due to the limited power output ?
- WCRs to be able to provide a mix of products
  - Electricity, process heat, water, hydrogen, transportation
- Deal with schedule and resources needed to adopt new technologies
  - Stepwise evolution of design features
  - Technology must be “extra-proven”, better science may help
  - Ensure that large R&D infrastructure needed is available for a long time
  - Interest to speed up the way of innovative features

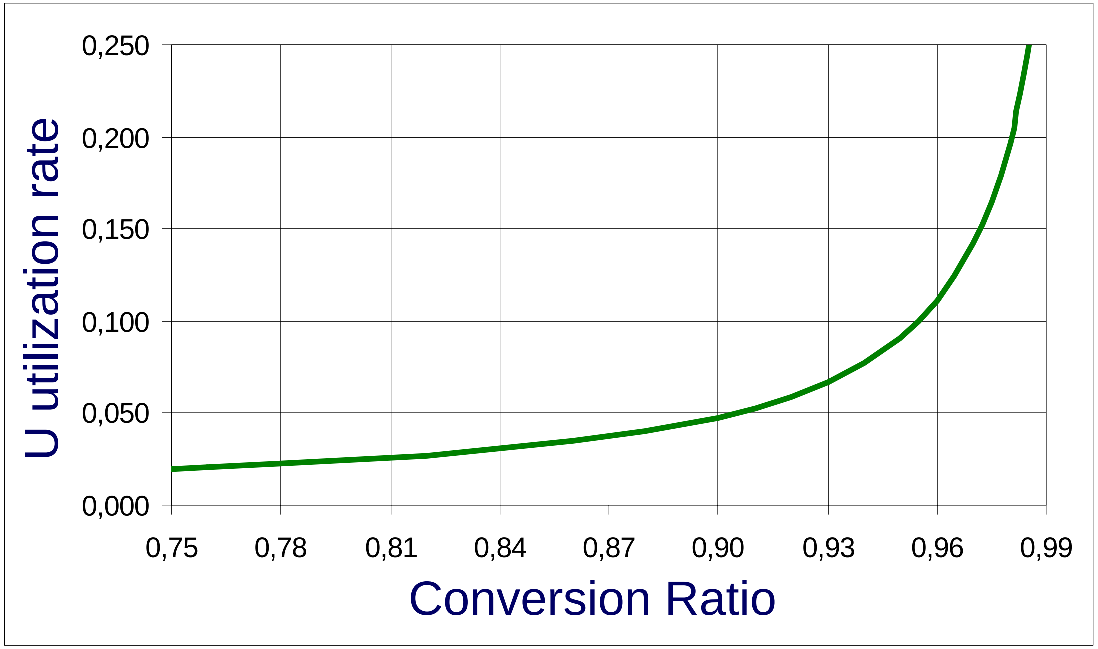
Reduce Natural Uranium Needs of WCRs

- Only breeders with a closed fuel cycle can provide full sustainability
- Should WCRs be deployed on a large scale, then natural uranium resource may become scarce
  - Is there is enough natural uranium for fueling WCR built until the breeders start coming on line? If yes, then open fuel cycle is a possible option during first part of the century
  - Alternative strategy: to reduce natural uranium needs of WCRs in order to gain some flexibility
- Optimize the use of reprocessed fuel
  - Use of MOX fuel and re-enriched reprocessed U in WCRs provide resource saving (≈ 25%)
  - Already implemented to a certain extend in some countries
    - Very limited technology impact: many present reactor designs can deal with 30% of fuel MOX assemblies per reload

Reduce Natural Uranium Needs of WCRs

Increase conversion ratio of the WCRs

Be ready to deploy this new reactors between the 3rd and the 4th generation



Processing loss rates (0.1%) - U depleted content (= 0.2%)

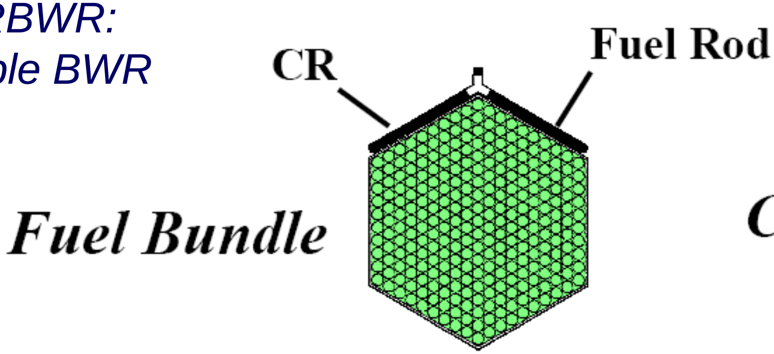
The highest the conversion ratio, the less penalizing the quality of the discharged Plutonium

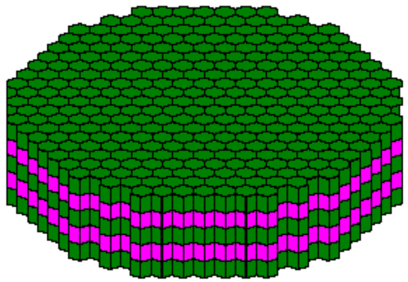
Reduce Natural Uranium Needs of WCRs

- Reduce moderating ratio in order to achieve a harder neutron spectrum and to increase the conversion ratio for U-Pu fuel cycle (target 0.9 or above)
  - Thermal-hydraulic challenge: in LCR the water is also used fuel cooling
  - Structural challenge: account for tight tolerance in core design
  - Safety criteria shall be met, e.g.:, Ensure negative void coefficient …

➔Industrial feasibility of high conversion ratio LWR yet to be proven

From Japanese RBWR: Resource-Renewable BWR





Fuel Rod diam. 10.1mm
Gap Width 1.3mm

Reduce Natural Uranium Needs of WCRs

- Investigate use of thorium as fertile material in WCRs
  - Th232-U233 may be an easier way to achieve high conversion ratio in thermal neutron spectrum core
  - ☹Reprocessing and manufacturing thorium-based fuel is difficult
  - ☺Minimization of minor actinides generation, resistance to proliferation (maybe)

Other Topics

- Safety
  - Some of the latest designs have already achieved an outstanding safety level
    - Interest of a consensus about the safety approach
- Proliferation
  - Proliferation resistance is not a true technical issue for LWR
    - UOX fuel use low enriched uranium
    - Discharged burnup is high enough to produce unattractive plutonium
  - Support IAEA safeguard

Other Topics

- Wastes: the Achille's heel for nuclear
  - Volume is small, short and long term technical answer exist
  - There is no urgency, but it is not a justification to do nothing!
    - Reduced the amount of waste: high burnup fuel / thorium-based fuel
    - Prepare fuel cycle closure: it is needed by utilities and plutonium is a valuable fissile resource that should not be
- Normal radioactive discharge
  - Gaseous and liquid releases of low-level radioactive isotope (i.e. tritium) : Are currently allowable discharge level well suited ?
- Site and Transmission Line
  - Reduce land use, reduce need for exclusion zone
  - Encourage interconnection among regional grid

Conclusion

- WCRs are the only realistic technology in the first part of 21st century
  - Mature technology → take advantage of experience
  - Bridge technology to Gen IV designs
- Need for WCRs to evolve and adapt to future needs
  - Thrive not just survive
- Continue to develop WCR technology that meet the expectations of future customers for as long as needed
  - No major impediment identified
  - Many new avenues of development to be investigated => will required large R&D programs

The Future Role of Light Water Reactors in the 21st Century

AREVA's view

Bernard Guesdon
AREVA Research and Innovation

October 2009

AREVA

The Future Role of LWR in the 21st Century
AREVA's view

Goals globally in line with those of the IAEA White Paper

A stepwise approach

- **Support utilities for achieving successful operation of present NPPs**
  - Optimized reactor and fuel performances
  - Extension of originally foreseen lifetime
- **Rely on evolutionary designs for new built**

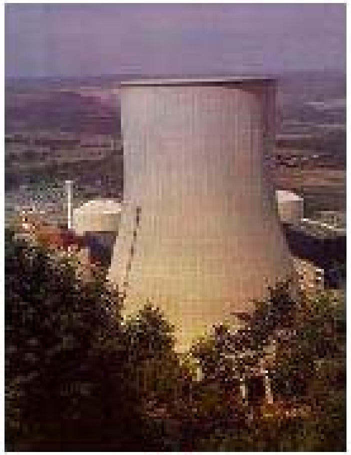
  EPR™ – ATMEA1™ – KERENA™
  - Differences in national requirements and licensing process add uncertainties on cost and time schedule; benefit expected from harmonization approach
  - In every case: Exhaustive, progressive and robust safety approach
Protection against Air Plane Crash
Only light protective measures in case of a severe accident

AREVA

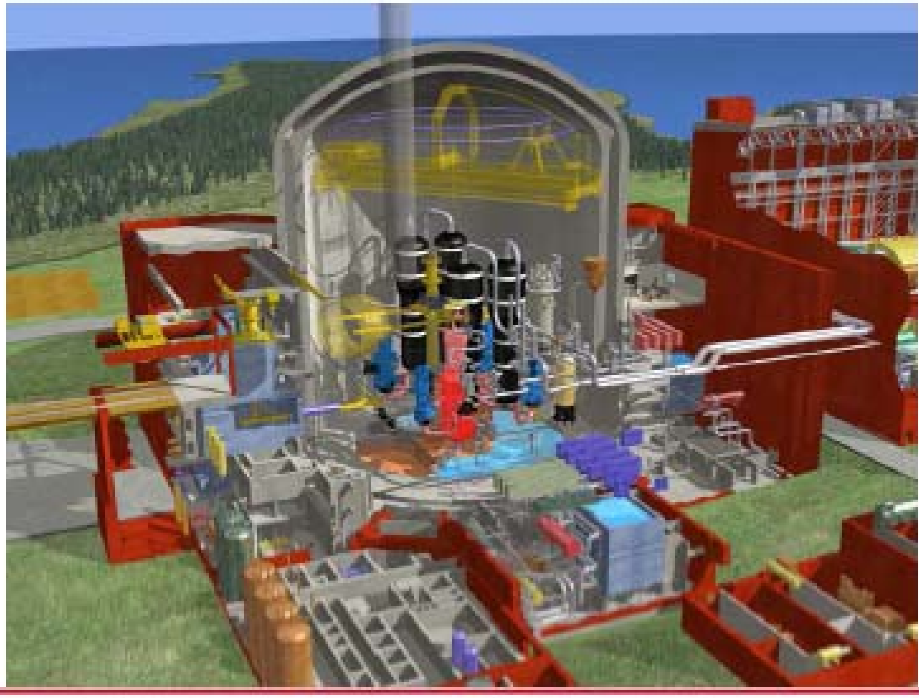
EPR™: The Flagship Reactor

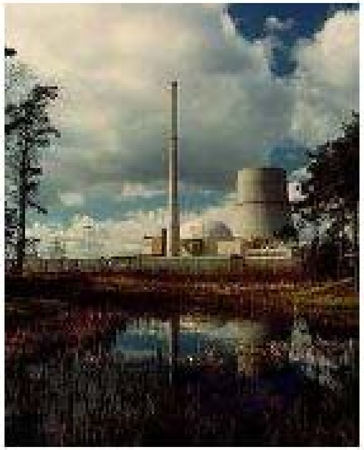
1600+ MWe Pressurized Water Reactor

- Developed with the support of French and German utilities
- Harmonized requirements of French Safety Authority and German experts and European Utilities (EUR)
- Evolutionary design based on experience from the most recent French and German PWRs



N4
- Chooz 1- 2
- Civaux 1-2





KONVOI
- Neckar 2
- Emsland
- Isar 2

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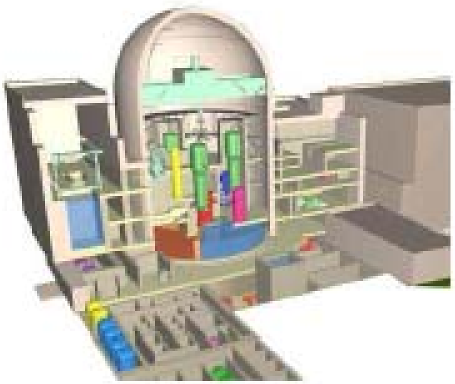
New LWR Designs

Meet different power requirements and technology choices

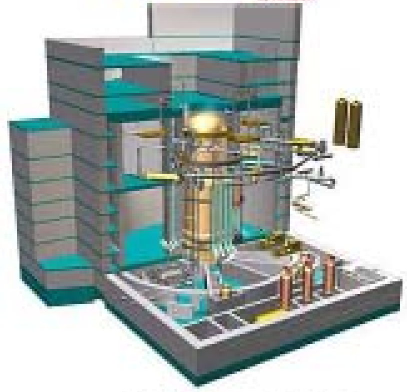
ATMEA1



1100+ MWe
Pressurized Water Reactor

Developed by ATMEA, a joint venture between AREVA and Mitsubishi Heavy Industry, Ltd.

KERENA



1250+ MWe
Boiling Water Reactor

Developed in co-operation with several European utilities, and in particular with German utility E.on

For both: Maximum availability and minimal environmental impact

Enhancing the uranium utilization rate in LWRs

- Look forward for future design improvements and for opportunity to deploy LWRs with a high conversion factor between the 3rd to the 4th generation of reactors
  - Feasibility of High Conversion Ratio in LWR is technically challenging and feasibility has to be confirmed (safety analysis)
- Operate and extend a comprehensive close fuel cycle
  - Fuel reprocessing
  - Plutonium and uranium recycling
  - Wastes conditioning
- For the long term, support the program on 4th generation of reactors (mainly SFR) conducted by the French CEA
  - Making full use of fertile material resources by the way of breeder reactors will secure the nuclear option sustainability

Thank you for your attention