Achievements and Prospects for Advanced Reactor Design and Fuel Cycles

Roberto O. Cirimello
Argentina

Advanced Designs

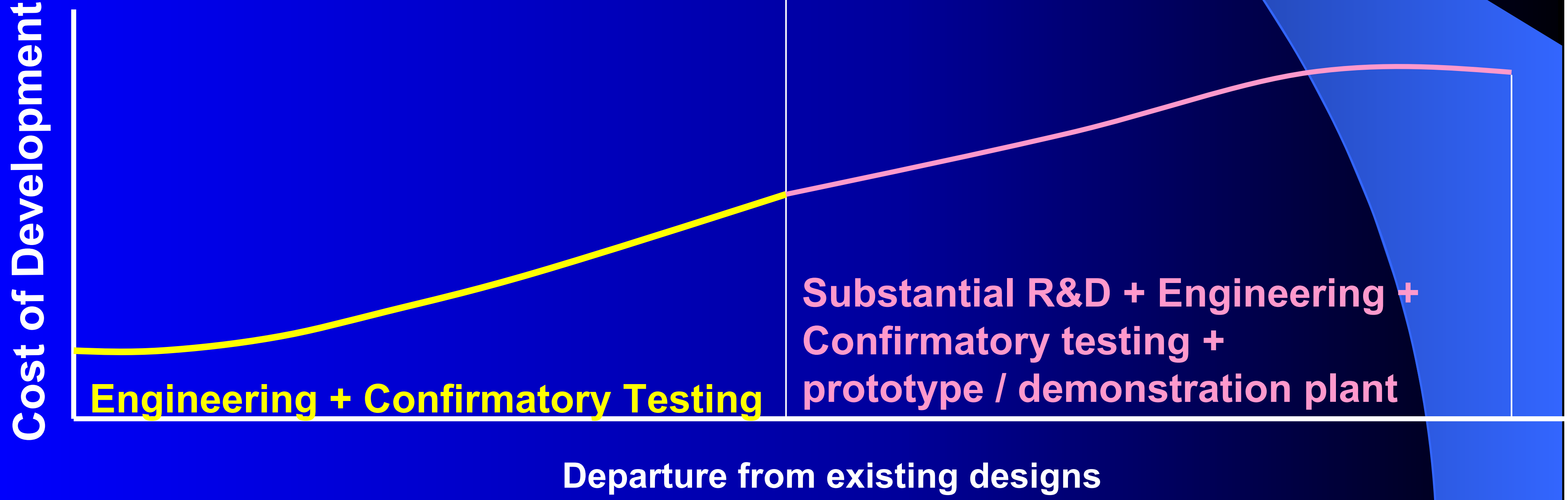
Consist of evolutionary designs and design requiring substantial development effort. It can range from moderate modifications of existing design to entirely new design concepts.

Evolutionary Design

Advance design achieving improvements over existing designs through small or moderate modifications (strong emphasis on maintaining proven design features to minimize technological risks)

Innovative Design

Advanced design that incorporates radical conceptual changes in design approaches or system configuration in comparison with existing practice



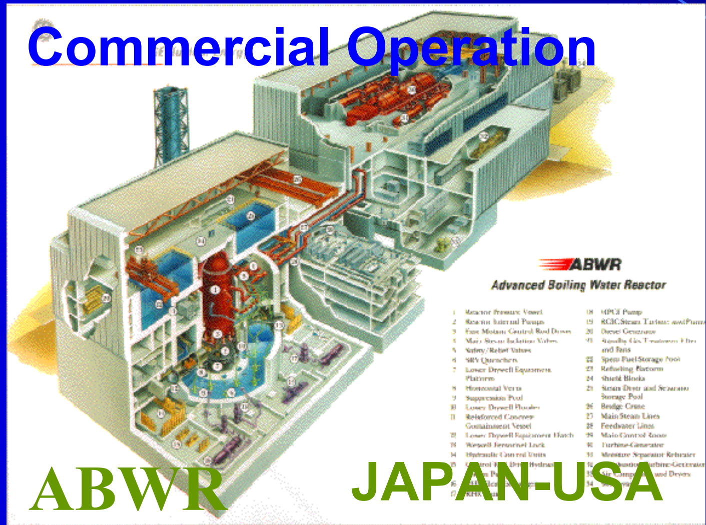
ACHIVEMENTS

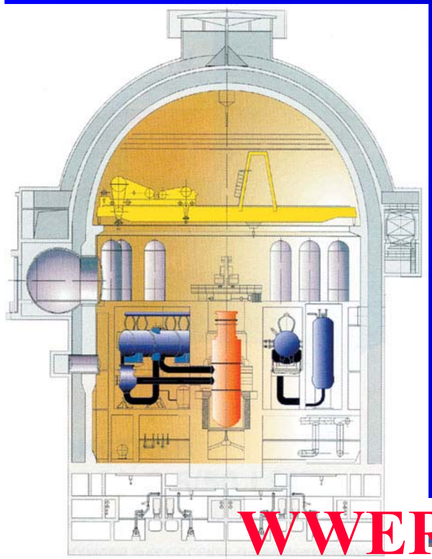
Let´s them believe...

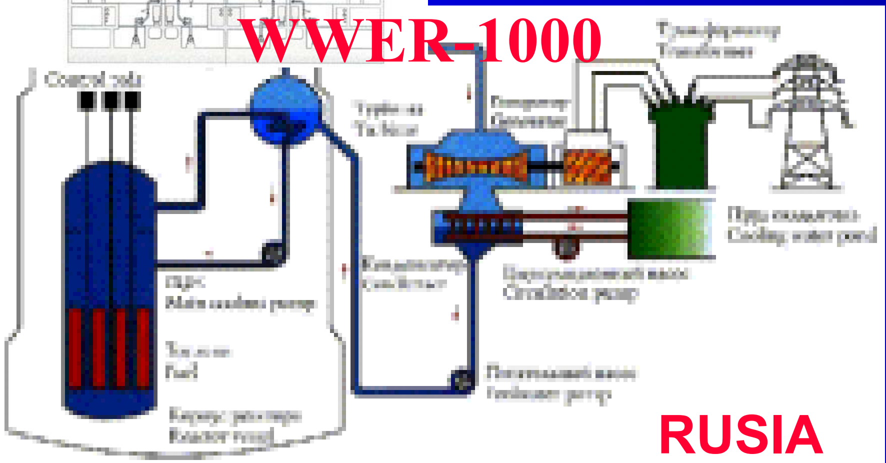
Evolutionary designs or third - generation reactors have:

- A standardized design for each type to expedite licensing, reduce capital cost and reduce construction time,
- A simpler and more rugged design, making them easier to operate and less vulnerable to operational upsets,
- Higher availability and longer operating life - typically 60 years,
- Reduced possibility of core melt accidents,
- Minimal effect on the environment,
- Higher burn - up reduce fuel use and the amount of waste,
- Burnable absorbers ("poisons") to extend fuel life.

Ligth and Heavy Water Reactors

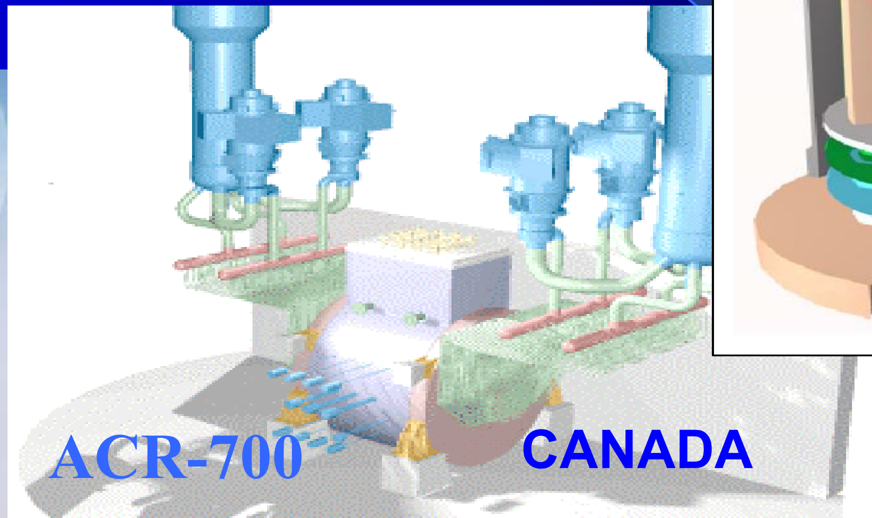


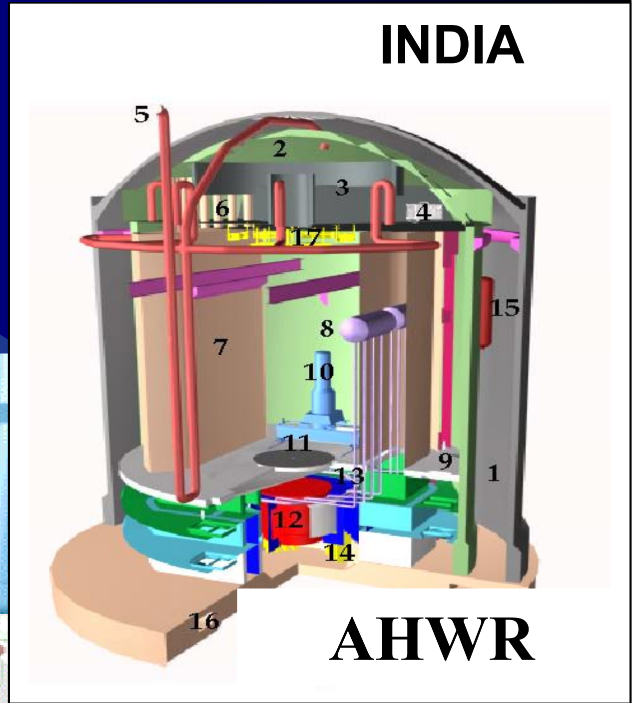




- Improved Safety
- Low cost electricity
- High fuel efficiency
- 60 years plant life, 48 m construction
- Less waste

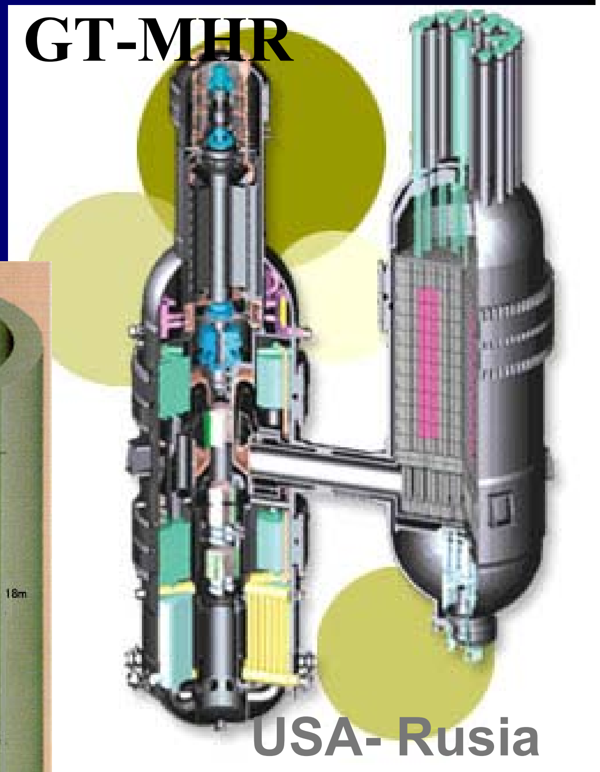
Ligth and Heavy Water Reactors

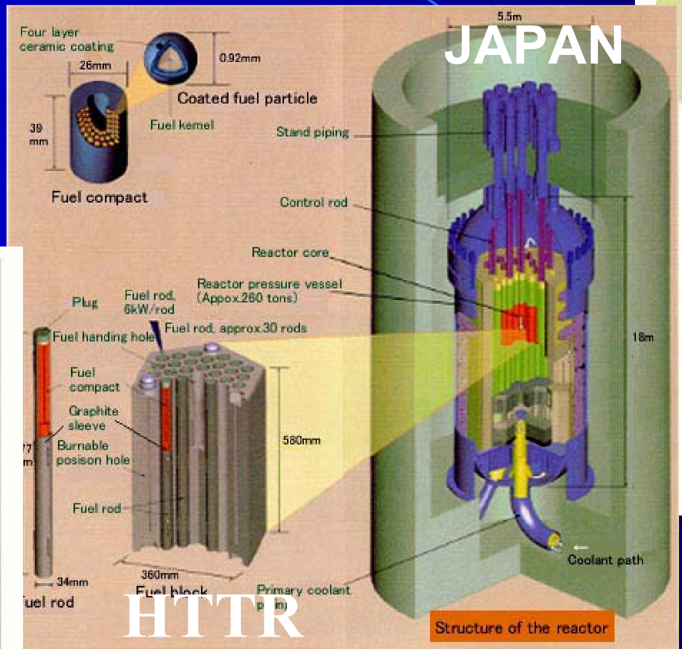


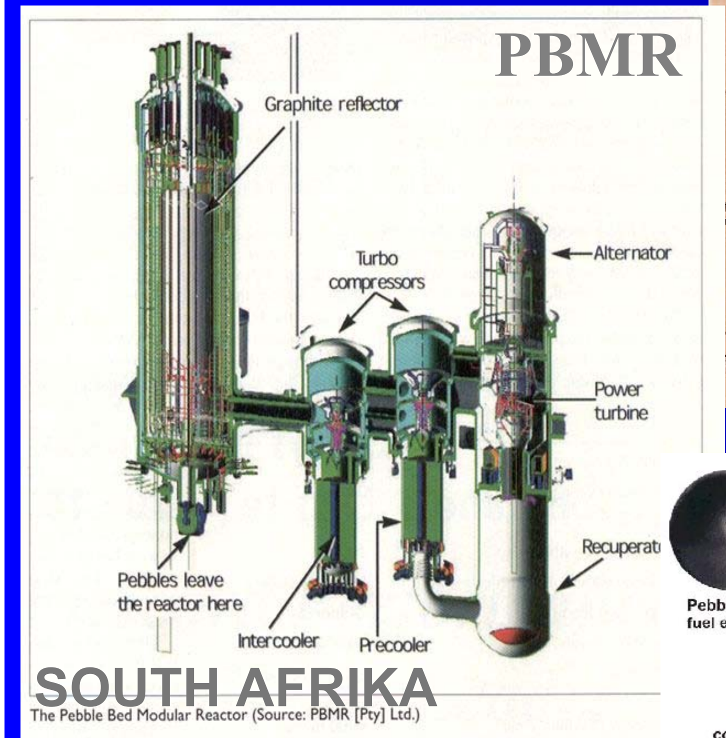


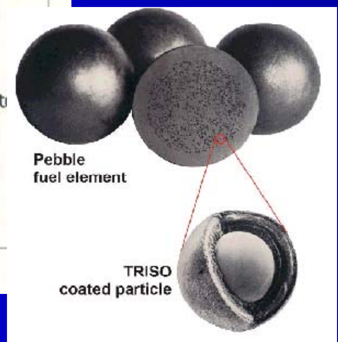
- Improved Safety
- Low cost electricity
- High fuel efficiency
- 60 years plant life, 48 m construction
- Less waste

Gas Cool Reactors





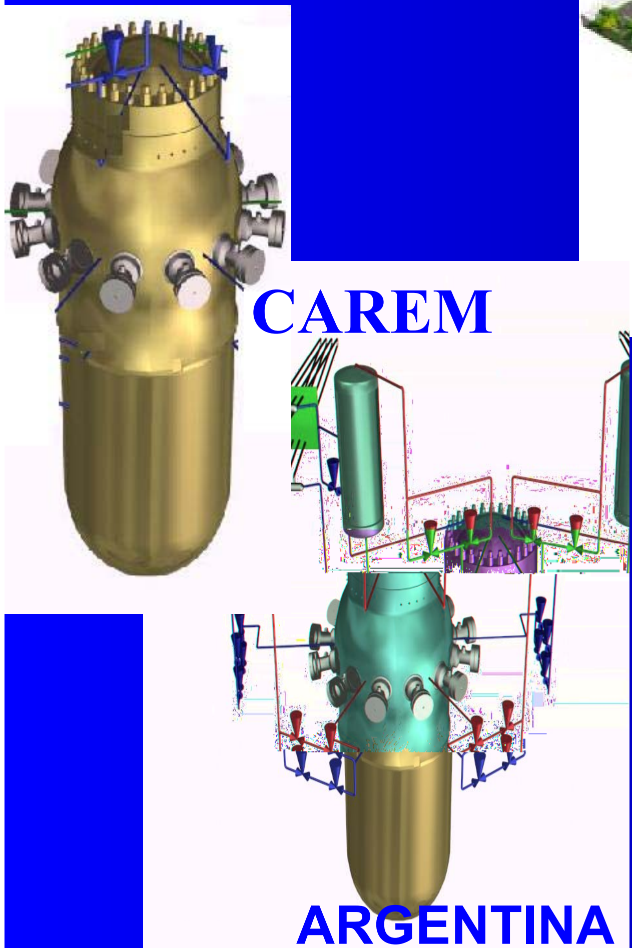


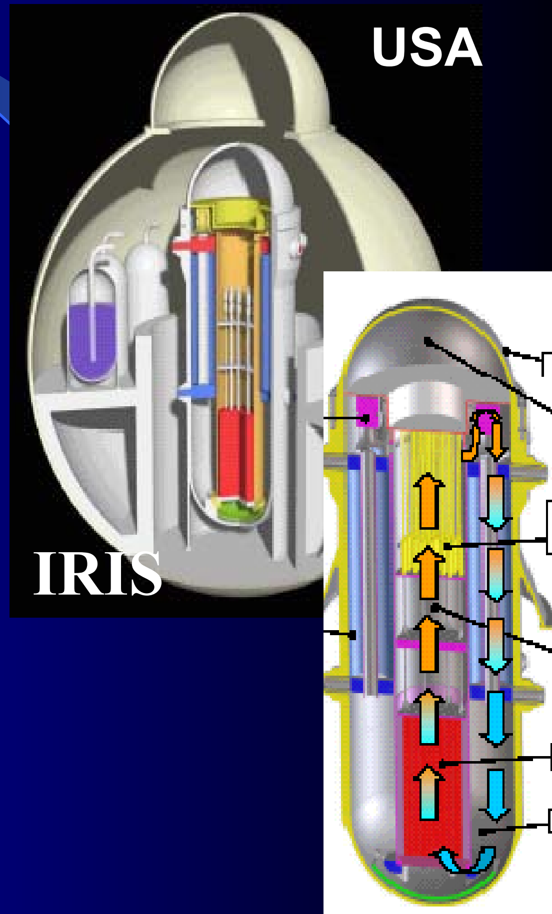


- Modular Plants
- Low cost
- Direct cycle gas turbine
- High fuel efficiency
- Passive safety features

Small & Medium Power Reactors

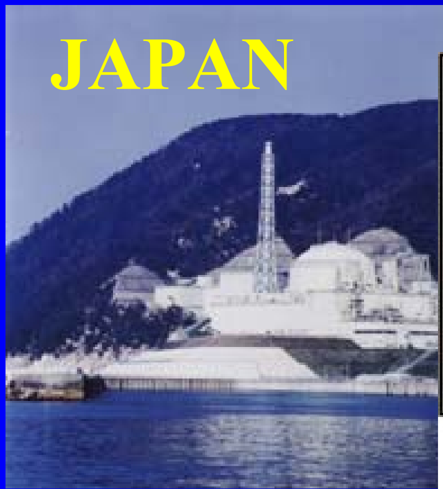
Also: Russia - Japan - India - Canada

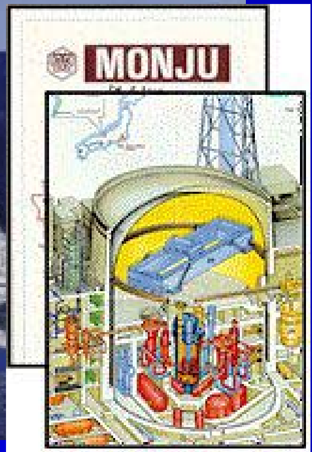


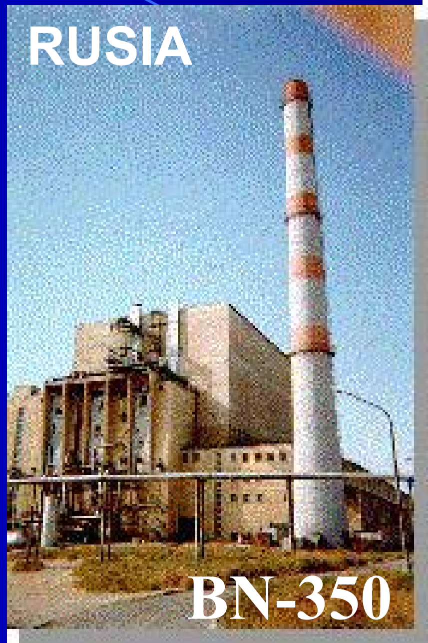


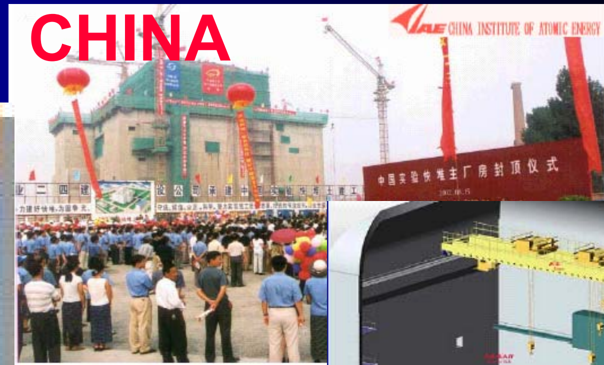
- ❖Modular Plants
- ❖Passive features
- ❖Non-electrical application
- ❖36 m construction
- ❖1000 $/KW install

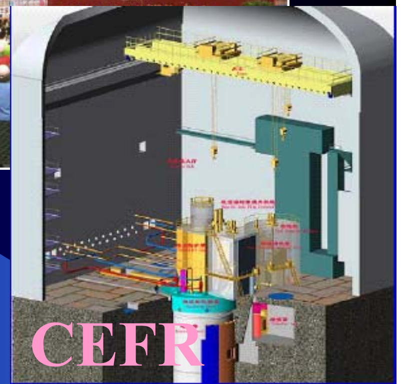
Fast reactors











- @ Recycling Pu
- @ Actinide burning
- @ Desalination
- @ Th Cycle

Key research areas of NRC´s Advanced Reactor Research Program

- **1. Accident Analysis -** risk assessment techniques, human factor tools, models to address advancements in instrumentation and control (I&C).
- **2. Reactor Systems Analysis -** thermal-fluid dynamics, nuclear analysis, and severe accident codes and models.
- **3. Fuels Analysis** - methods to assess coated fuel particle performance and higher burnup fuels.
- **4. Materials Analysis -** codes and standards to address metallic and graphite components under high temperature operating and accident conditions.
- **5. Structural Analysis -** methods to assess aging, degradation and impact of external events.
- **6. Consequence Analysis -** tool enhancements to address differences in the mix of radionuclides and chemical forms.

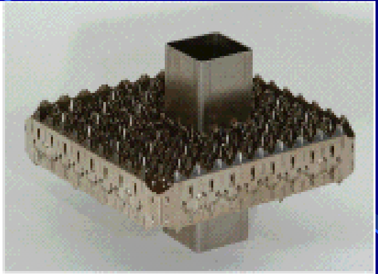
Safety goals for future NPP from IAEA´s Safety Standards and INSAG documents:

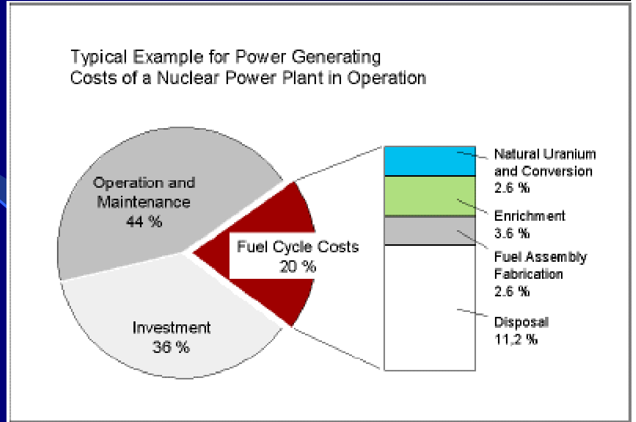
- 1. A reduction in core damage frequency (CDF) relative to current plants;
- 2. Consideration of selected severe accidents in the design of the plants;
- 3. Ensuring that the releases to the environment in the event of a severe accident are kept as low as practicable with the aim of providing a technical basis for simplification of emergency planning.
- 4. Reduction of the operator burden during an accident by an improved man-machine interface.
- 5. The adoption of digital instrumentation and control.
- 6. The introduction of passive components and systems.

Advanced technologies in the Front end of the NFC

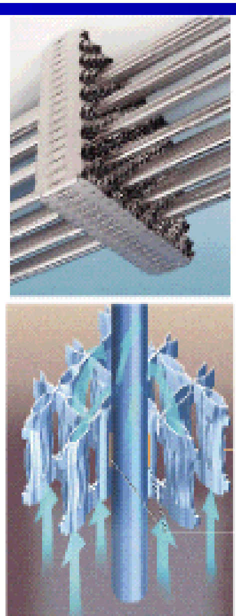
Fuel Assembly Design...

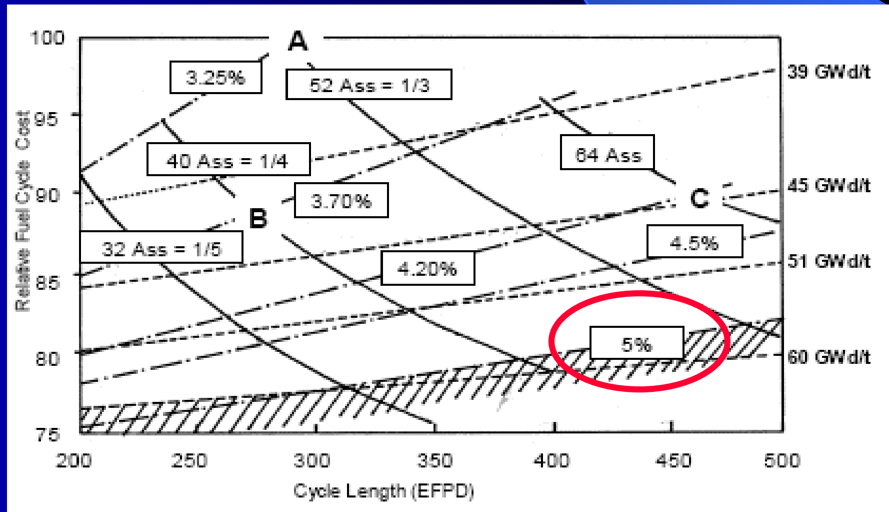
- Fuel assembly structure with internal water channel enables optimum moderation and thus best fuel utilization
- ULTRAFLOW™ spacer for excellent dryout performance
- Part length fuel rods for optimum axial fuel distribution and favorable stability performance
- High efficiency FUELGUARD™ debris filter





- Spacer grids with optimized swirl vanes provide enhanced thermal-hydraulic performance
- HTP spacer grids featuring line contact provide improved fretting resistance
- Reinforced structure provides high margins with respect to assembly bow (MONOBLOC™ guide tubes)
- High efficiency bottom nozzles (FUELGUARD™, TRAPPER™) effectively retain debris thus preventing fretting damage to the fuel rods
- Advanced cladding material M5™ provides outstanding margins with respect to corrosion, hydriding as well as creep and growth



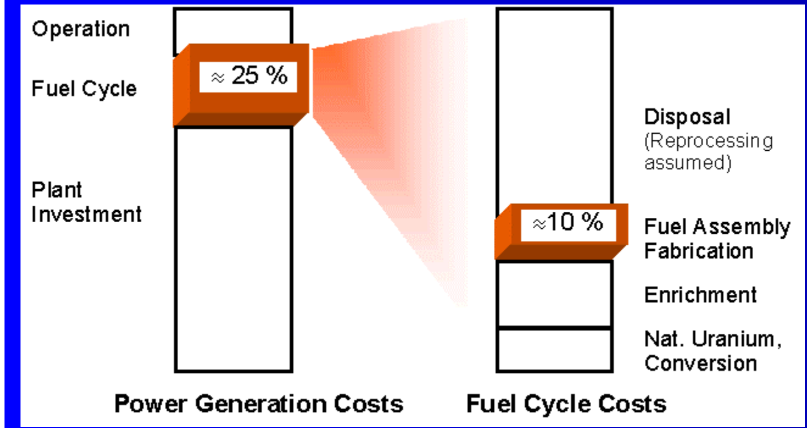


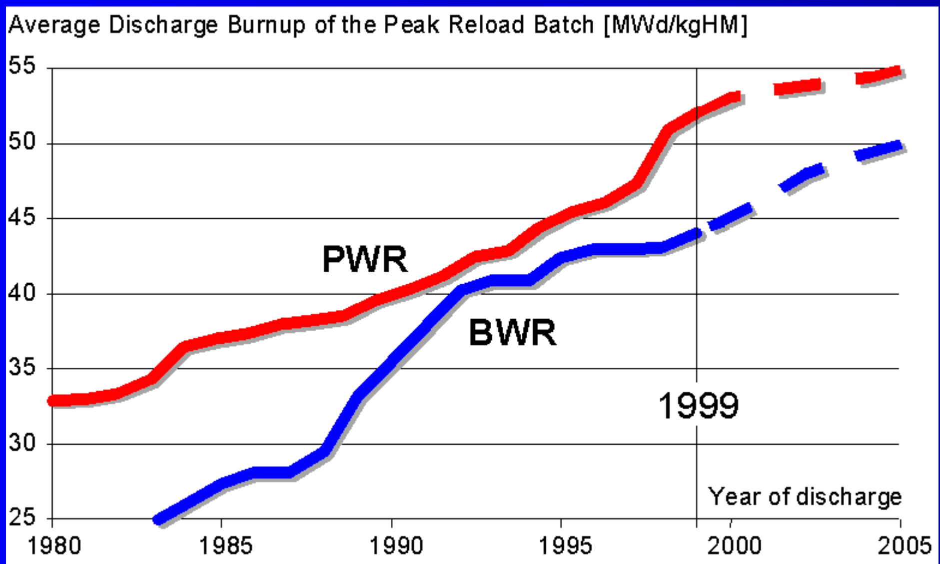
"Framatom ANP extended burnup experience and views on LWR fuels. Michel Watteau et al." WNA-2001

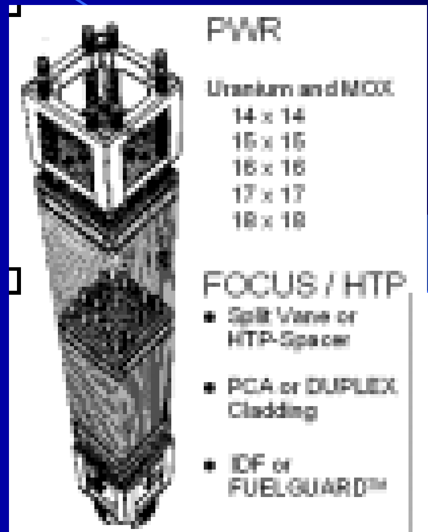
Relative Fuel Cycle Cost

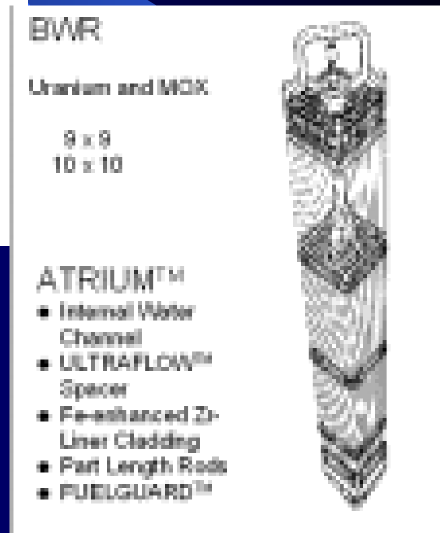
Advanced technologies in the Front end of the NFC

Fuel Assembly Design...







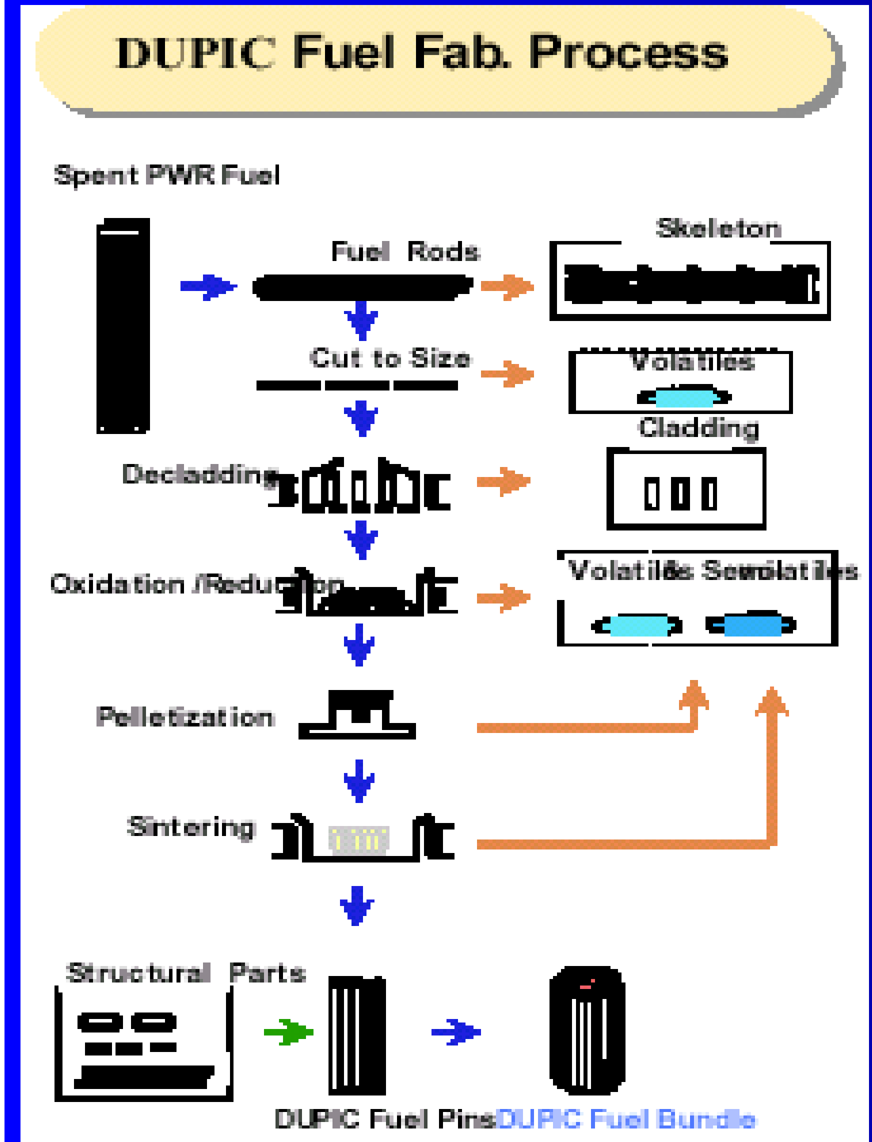


"Contribution of Advanced Fuel Technologies to Improved Nuclear Power Plant Operation

Ralf Güldner & Friedrich Burtak – Siemens

Advanced Technologies in the Back-End of the NFC

Reprocessing...



DUPIC = Direct Use of PWR spent fuel In CANDU

DUPIC cycle anticipated benefits:

- **Save of Unat for CANDU due to the reuse of PWR spent fuel.**
- **Removal of PWR spent fuel**
- **Reduction of CANDU spent fuel due to the increase of burnup**
- **Environmental benefit due to the transmutation effect of burning again PWR spent fuel.**

DUPIC can be apply in countries with LWR and HWR at the proportion of 4 by 1.

PROSPECT...

Gaze Into The Crystal Ball...

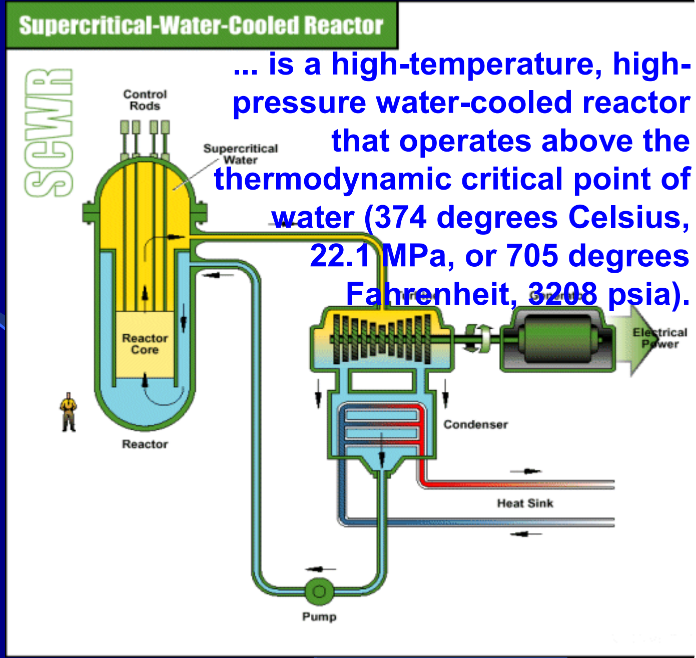
Generation IV Technology Goals

Generation IV nuclear energy systems will:

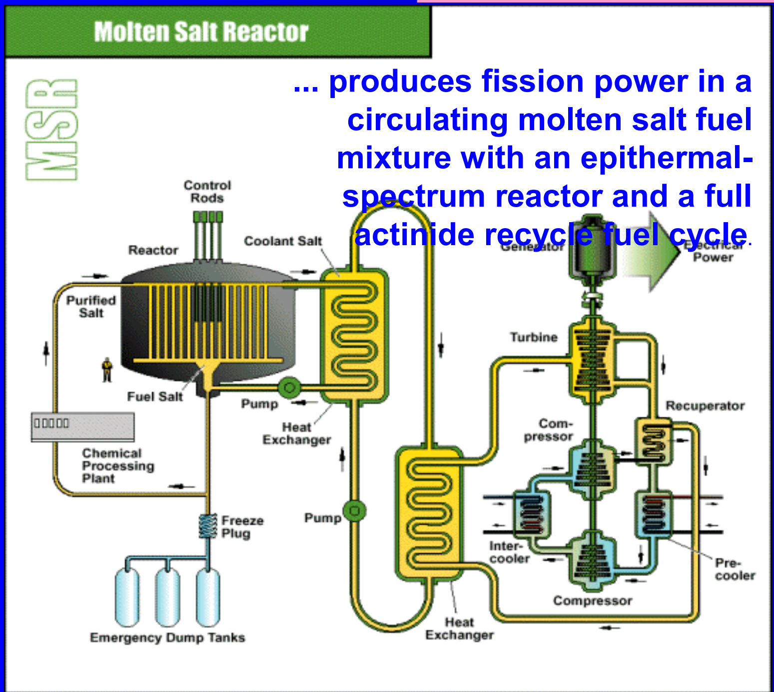
- ❖ Provide sustainable energy generation that meets clean air objectives and promote long-term availability of systems and effective fuel utilization for worldwide energy production
- ❖ Minimize and manage their nuclear waste and notably reduce the long term stewardship burden in the future, thereby improving protection for the public health and the environment.
- ❖ Increase the assurance that they a very unattractive and least desirable route for diversion or theft of weapon-usable materials.
- ❖ Excel in safety and reliability.
- ❖ Have a very low likelihood and degree of reactor core damage.
- ❖ Eliminate the need of offsite emergency response.
- ❖ Have a clear life-cycle cost advantage over other energy sources.
- ❖ Have a level of financial risk comparable to other energy projects.

Gen IV Thermal Reactor Concepts

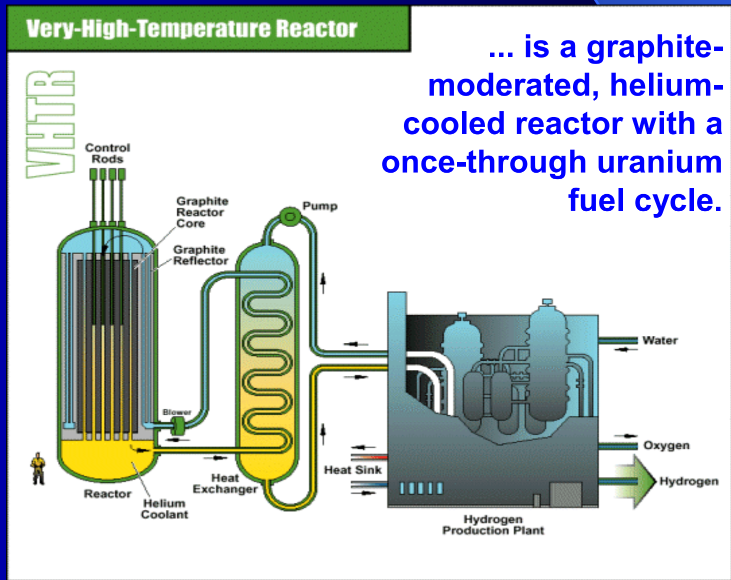
Comparative advantages include: reduced capital cost, enhanced nuclear safety, minimal generation of nuclear waste, and further reduction of the risk of weapons materials proliferation. The purpose of Gen IV is to develop nuclear energy systems that would be available for worldwide deployment by 2030 or earlier.



... is a high-temperature, high-pressure water-cooled reactor that operates above the thermodynamic critical point of water (374 degrees Celsius, 22.1 MPa, or 705 degrees Fahrenheit, 3208 psia).



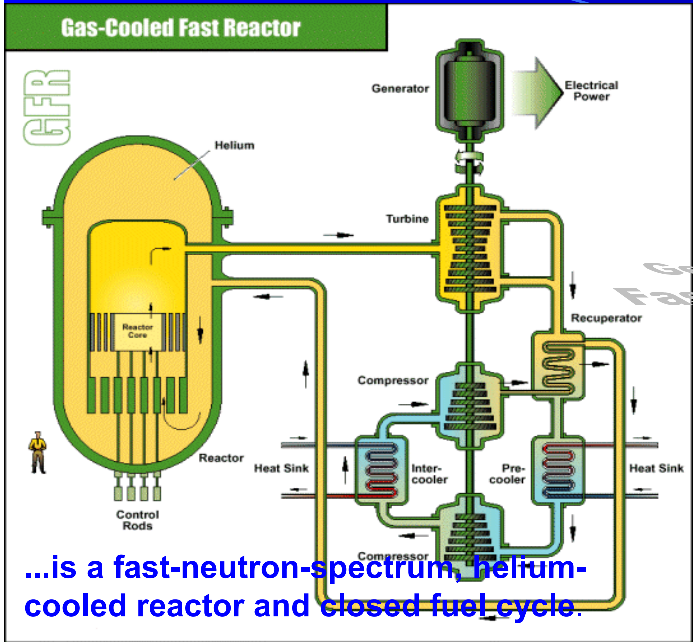
... produces fission power in a circulating molten salt fuel mixture with an epithermal-spectrum reactor and a full actinide recycle fuel cycle.



... is a graphite-moderated, helium-cooled reactor with a once-through uranium fuel cycle.

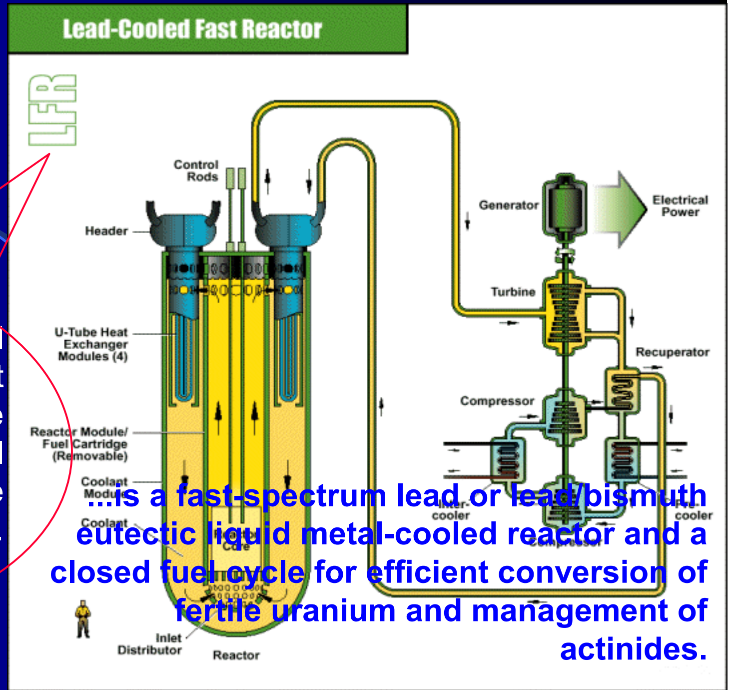
Gen IV

Fast Reactor Concepts

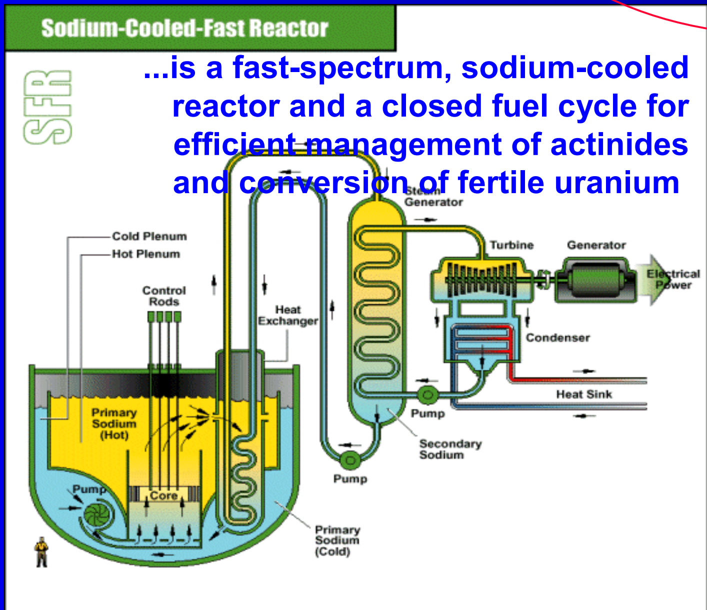


...is a fast-neutron-spectrum, helium-cooled reactor and closed fuel cycle.

The LFR battery is a small factory-built turnkey plant operating on a closed fuel cycle with very long refueling interval (15 to 20 years) cassette core or replaceable reactor module.



...is a fast-spectrum lead or lead/bismuth eutectic liquid metal-cooled reactor and a closed fuel cycle for efficient conversion of fertile uranium and management of actinides.



...is a fast-spectrum, sodium-cooled reactor and a closed fuel cycle for efficient management of actinides and conversion of fertile uranium

The GFR´s and SFR´s fast spectrum also makes it possible to use available fissile and fertile materials (including depleted uranium) considerably more efficiently than thermal spectrum reactors with once-through fuel cycles.

Advanced technologies in the Front end of the NFC

U Enrichment...

New enrichment technologies currently being developed

- atomic vapor laser isotope separation (AVLIS)
- molecular laser isotope separation (MLIS).
- Each laser-based enrichment process can achieve higher initial enrichment (isotope separation) factors than the diffusion or centrifuge processes can achieve. Both AVLIS and MLIS would be capable of operating at high material throughput rates.

•In 1985 the US Government backed it as the new technology to replace its gaseous diffusion plants. After some US$ 2 billion in R&D, it was abandoned in USA in favor of SILEX, a molecular process.

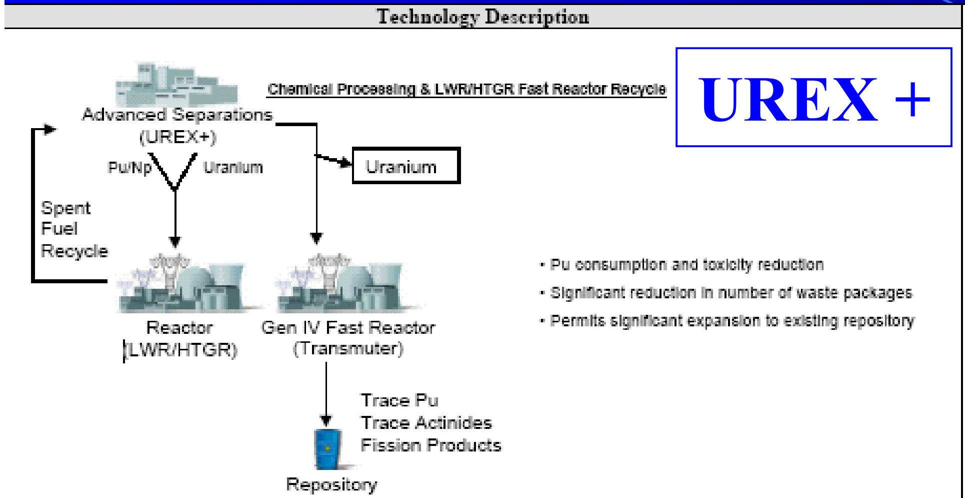
•Development of AVLIS, and the French SILVA began in the 1970s.

•French work on SILVA has now ceased but continuo the MLIS technology evaluation.

SILEX (Separation of Isotopes by Laser Excitation) Program (Molecular) (under USEC-Silex System Ltd. Australia until 2003) Now SSL alone: (I) Pilot Module Program (Completed January 2000) (II) Pilot Engineering Study (Second Half 2001) (III) Pilot Plant Program (???)

Advanced Technologies in the Back-End of the NFC

Reprocessing...

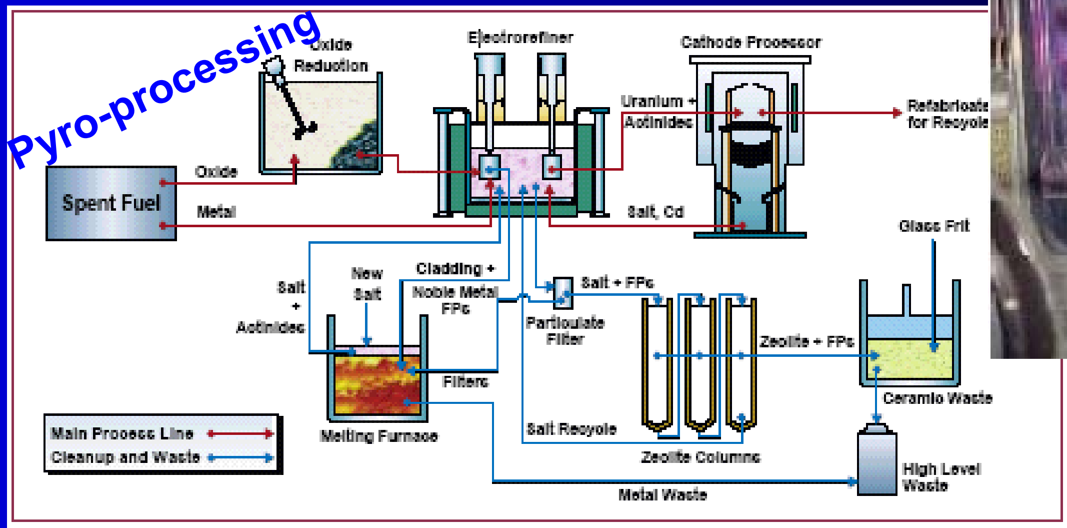


New approach of reprocessing are needed for:

- P & T or P & C
- NFC for FR
- ADS

Pyrometallurgical processes:

- Molten salt bath ($LiCl+KCl$ or $LiF+CaF_2$)
- Fuse Metals (Cd, Bi, Al)
- Electrochemical separation



IAEA INPRO PROJECT

INPRO (INternational PROyect on Innovative Nuclear Reactors and Fuel Cycle) objectives are:

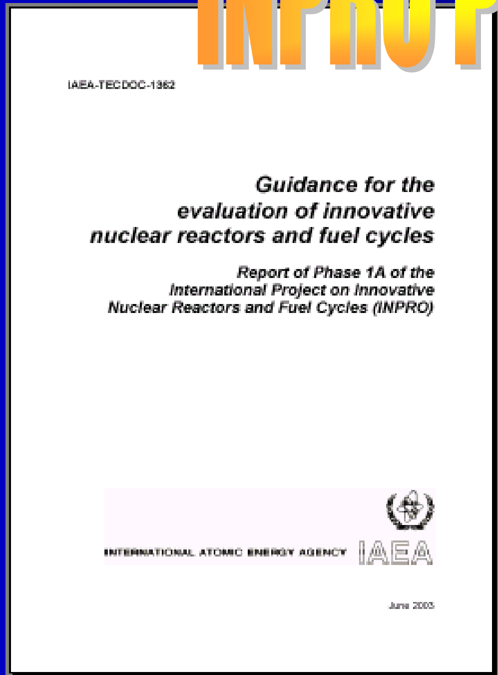
- ❑ Help to ensure that nuclear energy is available to contribute in fulfilling energy needs in the 21st century in a sustainable manner, and to
- ❑ Bring together both technology holders and technology users to consider jointly the international and national actions required to achieve desired innovations in nuclear reactors and fuel cycles.

INPRO

(INternational PROyect on Innovative Nuclear Reactors and Fuel Cycle)

Development of a Methodology for the Assessment of suitable INS for future deployment (Basic Principles User Requirements and Criteria on Economics, Sustainability and Environment, Safety, Waste Management, Proliferation Resistance and Infrastructure)

INPRO PHASE I


IAEA-TECDOC-1362

Guidance for the evaluation of innovative nuclear reactors and fuel cycles

Report of Phase 1A of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO)

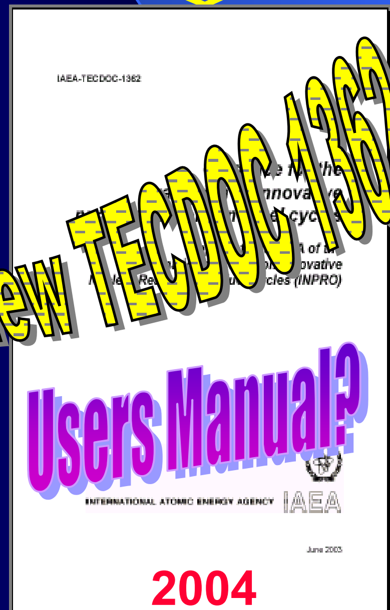
INTERNATIONAL ATOMIC ENERGY AGENCY IAEA

June 2003

2000/2002

Methodology Assessment throughout National and Individual Case Studies

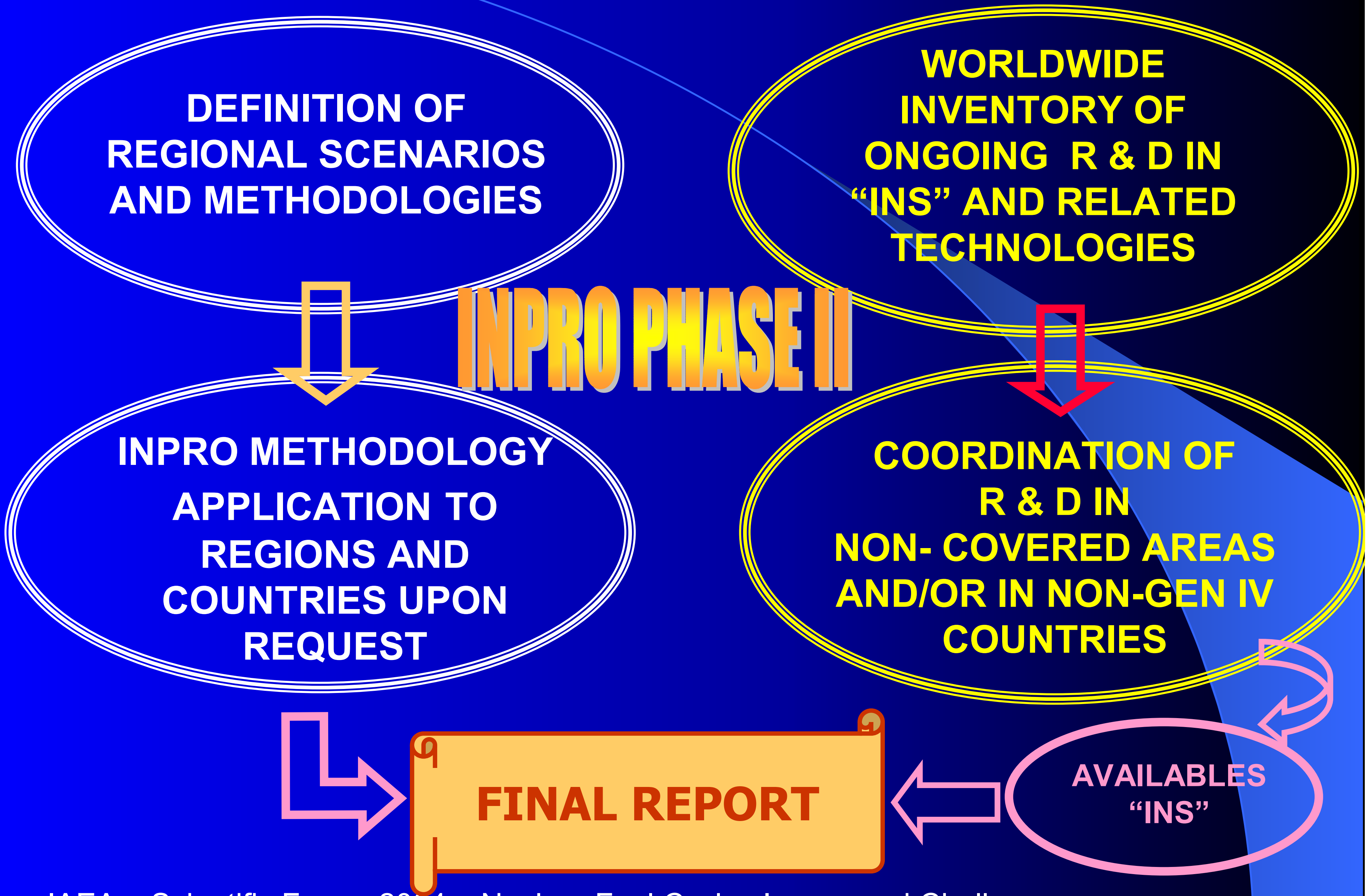
2003/2004

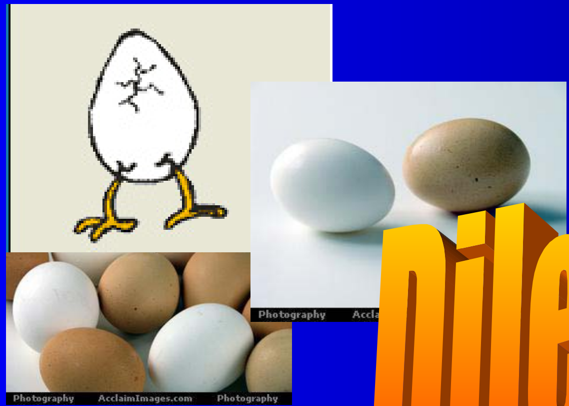


New TECDOC 1362

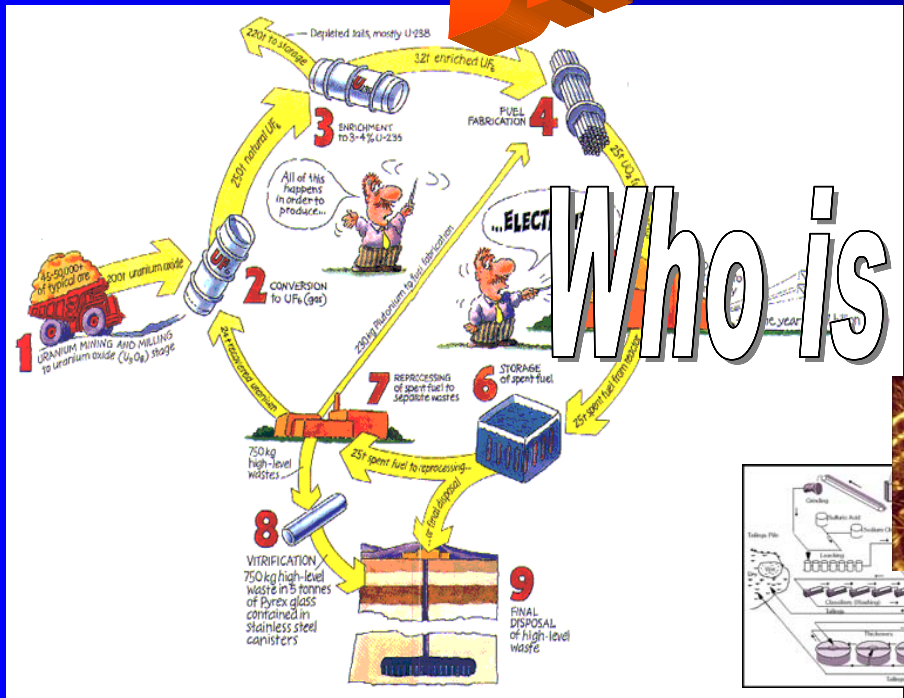
Users Manual?

2004

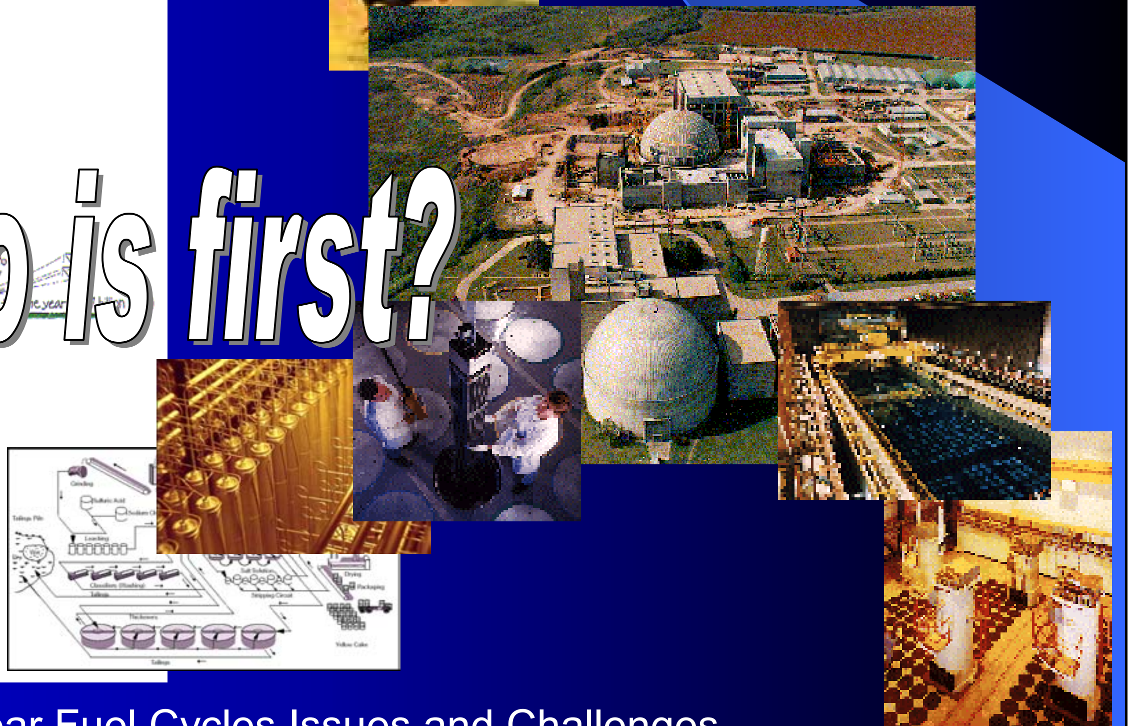

DEFINITION OF REGIONAL SCENARIOS AND METHODOLOGIES
WORLDWIDE INVENTORY OF ONGOING R & D IN "INS" AND RELATED TECHNOLOGIES
INPRO PHASE II
INPRO METHODOLOGY APPLICATION TO REGIONS AND COUNTRIES UPON REQUEST
COORDINATION OF R & D IN NON- COVERED AREAS AND/OR IN NON-GEN IV COUNTRIES
FINAL REPORT
AVAILABLES "INS"



Dilemma!!!

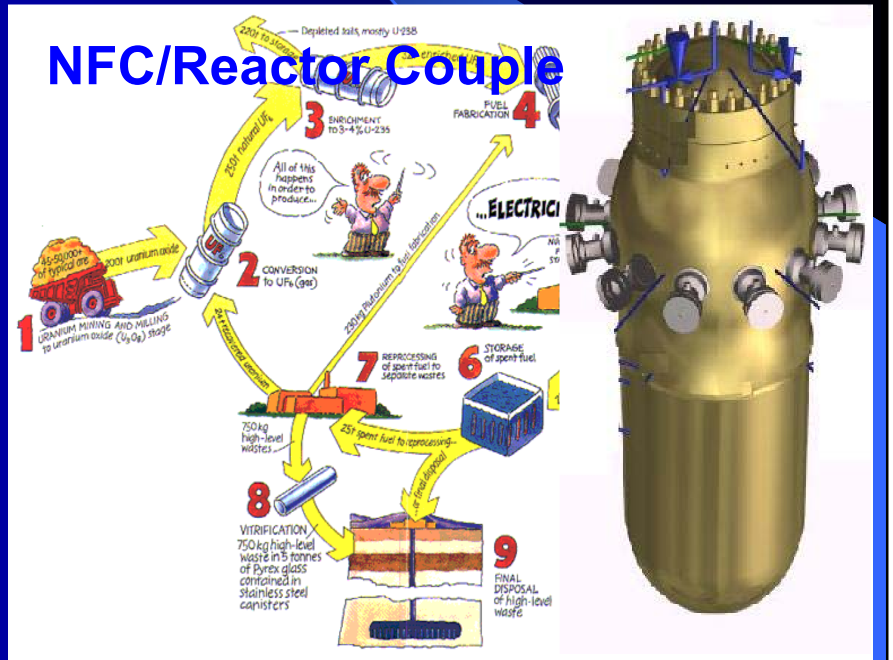


Who is first?



First Approach

¡For Tango we need two dancers!

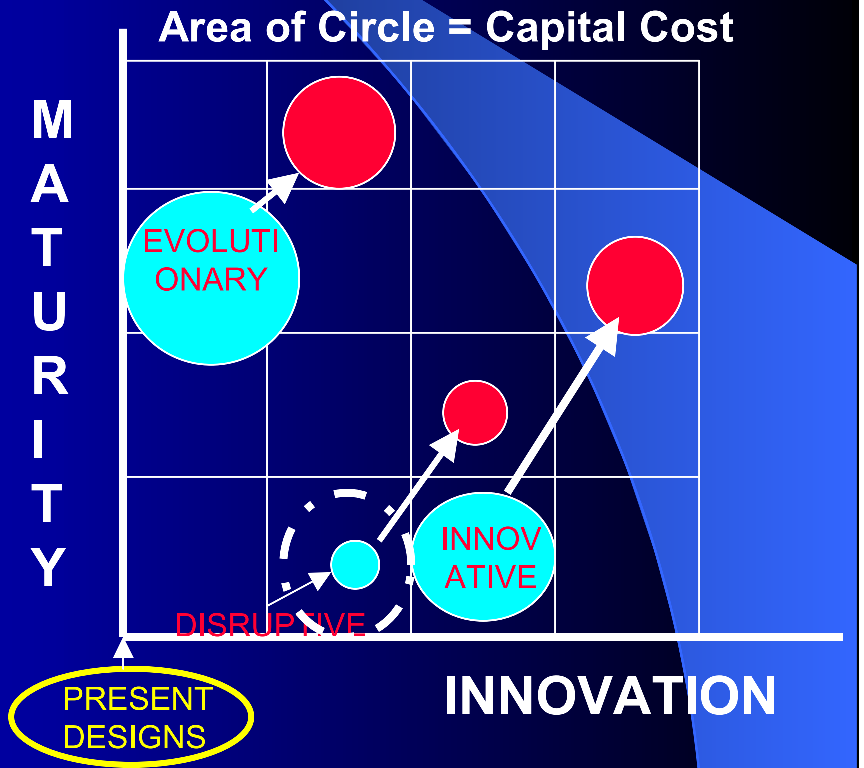


- **Burnup Increase increasing the enrichment. Only improved the Zry use.**
- **High Reactor efficiency with the results of higher cost of the NFC/Reactor system.**
- **Waste Storage is better at 700 m deep in isolate areas than in protected areas. Urge the decision of transport the spent fuel.**

Second Approach

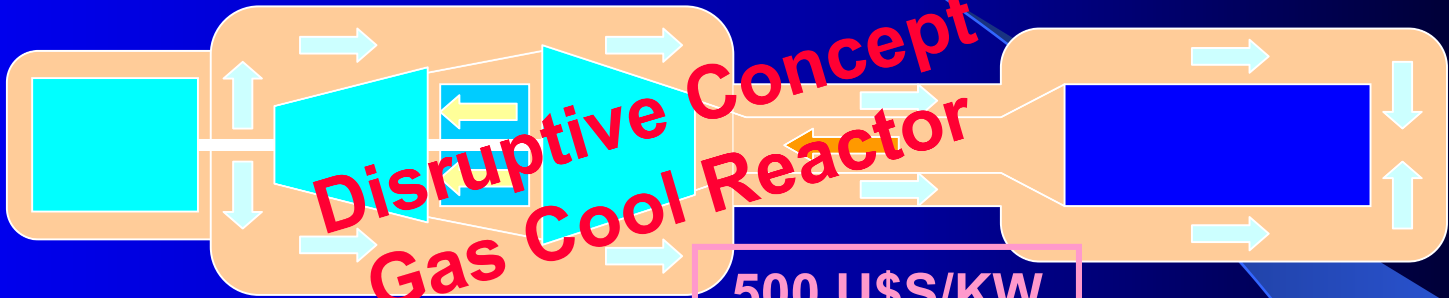
¡Disruptive technologies!

...upon C.M. Christensen definition

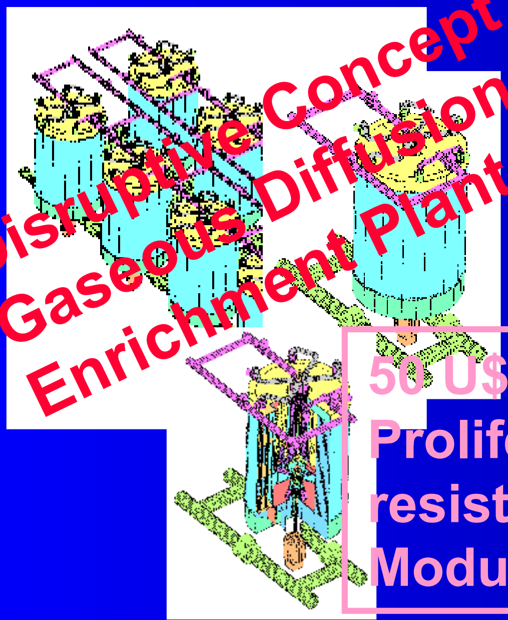


...is a technology that enter the market providing a product which has lower performance that the incumbent, but exceeds the requirements of certain segments thereby gaining a foothold in the market.

¡Disruptive technologies in INS!



500 U$S/KW



50 U$S/SWU
Proliferation resistant-
Modular Plant

Three time less expensive than metal casks

"Those who believe in progress run the risk of being born too early"

Oscar Wilde

Thank you very much...

...for your attention.