

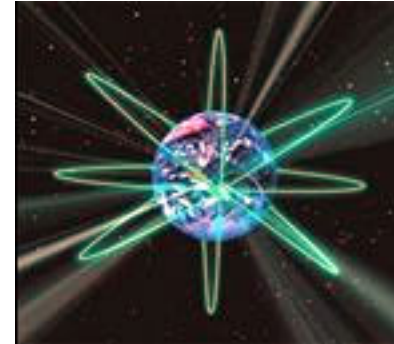
Revival of Nuclear Energy

(Part 3)

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Revival of Nuclear Energy in USA?

- Just a few years ago, many analysts were projecting the decline of nuclear power. Reality has proven these projections to be wrong. Dozens of plants have already begun or will soon begin the NRC license renewal process -- most, if not all, are expected to follow. The reasons for this reversal of nuclear fortunes are very clear:
- 1) Nuclear plants have performed exceedingly well. As a group, U.S. nuclear utilities have improved the availability of their plants from about 70 percent in 1990 to close to 90 percent today and are producing electricity at about 2 cents per kilowatt-hour (about the same as the most efficient natural gas plants);
- 2) Consolidation of the nuclear utility industry is leading to the formation of large nuclear utilities with tremendous efficiencies and expertise in operations, maintenance, and training and who have a long-term interest in nuclear power; and
- 3) The NRC has reformed its operation and has, with the success of its license renewal process, proven itself to be a fair and consistent regulator with which industry can work to continue operating new plants and potentially build new ones.

Revival of Nuclear Energy in USA?

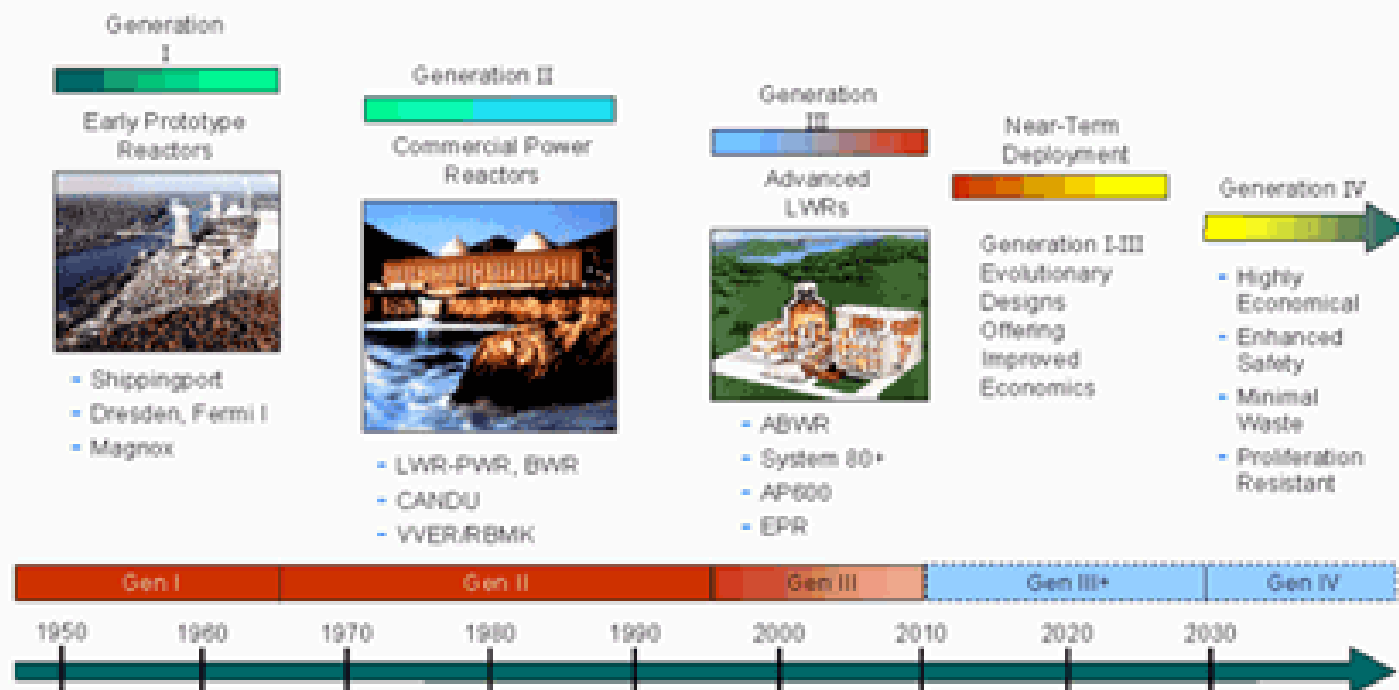
- **1997 - AmerGen bought the TMI Plant 1 for \$100 million, 70% of which was for fuel!**
- **1997 - Entergy bought Boston Edison's Pilgrim plant for \$13 million, plus \$67 million for fuel!**
- **It was a buyer's market and remained that way throughout 1999, when several smaller plants were sold for similarly depressed prices!**
- **1999 - NRC renewed the license for the Calvert Cliffs plant for additional 20 years.**
- **Suddenly, it was realized that many of NPPs built in the 1960s and 70s could have longer life spans than originally taught!**
- **AmerGen and Entergy looked like financial geniuses!**

Revival of Nuclear Energy in USA?

- The prospect of license renewals drew more potential buyers into the market for NPPs - the utilities began to hold auctions.
- 2000 - Entergy agreed to buy a pair of New York plants for close to a BILLION dollars.
- Soon after that, Dominion bid \$1.3 BILLION for the Millstone plant in Connecticut.
- BUYERS: “The high prices were justified because of competing fossil fuel energy costs kept rising, MAKING A NUCLEAR POWER A RELATIVE BARGAIN!”
- And then comes the California energy crisis.



The Evolution of Nuclear Power



Opportunities for new construction include

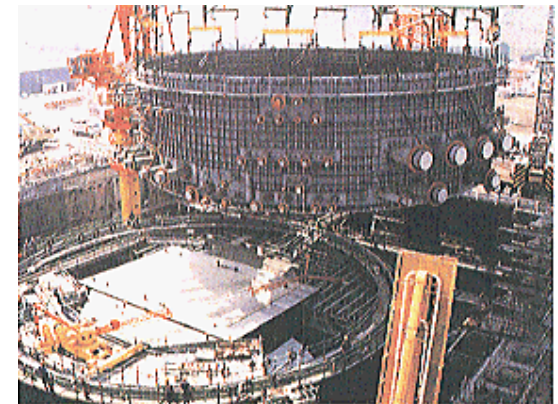
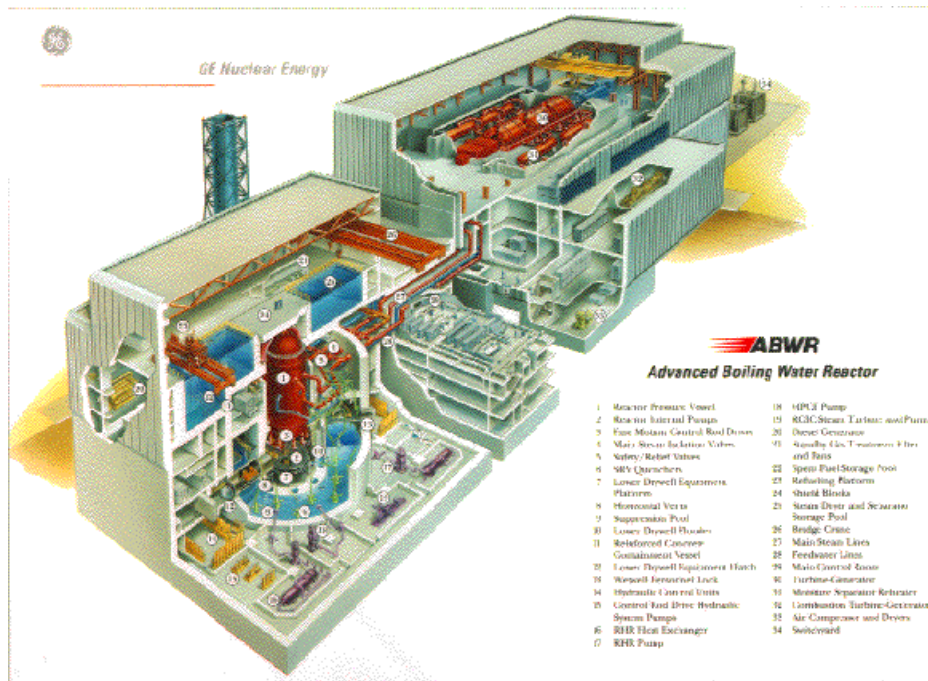
- Evolutionary Light Water Reactors
 - Advanced designs already certified by NRC
 - System 80+, **ABWR**
- Generation III+
 - Designs that can be certified and built in this decade
 - Developed under the DOE “Near-Term Deployment” effort
 - AP-1000, ESBWR, **PBMR**
- Generation IV
 - Advanced, integrated nuclear energy systems
 - Developed under the DOE “Generation IV Roadmap” effort
 - Goals: Sustainability; Safety and Reliability; Economics
- Fusion
 - Magnetic Fusion, **Inertial Fusion**

Generation IV Technology Roadmap

- **This Roadmap is scheduled to be completed by the end of FY 2002 and will:**
- **Draw upon a wide range of experts from government, national laboratories, industry, and academia;**
- **Set ambitious technology goals for next-generation systems;**
- **Identify the most promising concepts for advanced nuclear energy systems to meet future energy needs; and**
- **Identify the R&D activities needed to develop these concepts and make them ready for commercial deployment.**

Advanced Boiling Water Reactor

- “Evolutionary” design certified by NRC
- Developed by:
 - General Electric, San Jose, California
 - Hitachi/Toshiba, Japan
- 1350-MWe capacity
- 2 units constructed in Japan

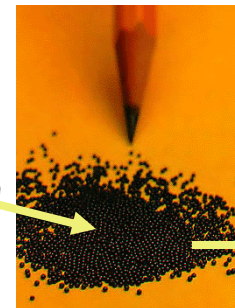
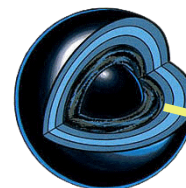


Modular assembly reduces construction time to 52 months

Escom and Entergy are exploring NRC design certification of the Pebble Bed Modular Reactor (PBMR)

- **Specifications:**

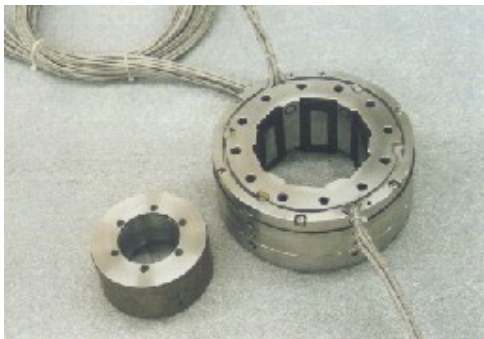
- 115 MWe modular high-temperature helium-cooled gas-turbine reactor
- Based on 15MWe German AVR that operated from 1967-1989
- Fuel temperatures:
 - » Average fuel: 1095°C
 - » Peak fuel shut-down: 1600°C
 - » Maximum tolerable: >2000°C
- Uses helium gas turbine (45% thermal efficiency)
- 3.5 m diameter x 10 m high graphite lined vessel; 440,000 6-cm diameter pebbles
- Power controlled by adding or removing helium coolant—no control rods
- Pebble recycling maintains constant reactivity and achieves very high fuel burnup
- Capital cost estimate: \$1,000/kWe
- Construction time estimate: 24 months



Upcoming PBMR milestones include start of prototype construction in 2001, criticality in 2004

- **Key attributes:**

- High power density of gas turbines
- Shutdown heat removal always on--no moving parts
- Very high fuel burn up (~15%) reduces waste generation
- Issues:
 - » Fuel performance
 - » Confinement vs. containment



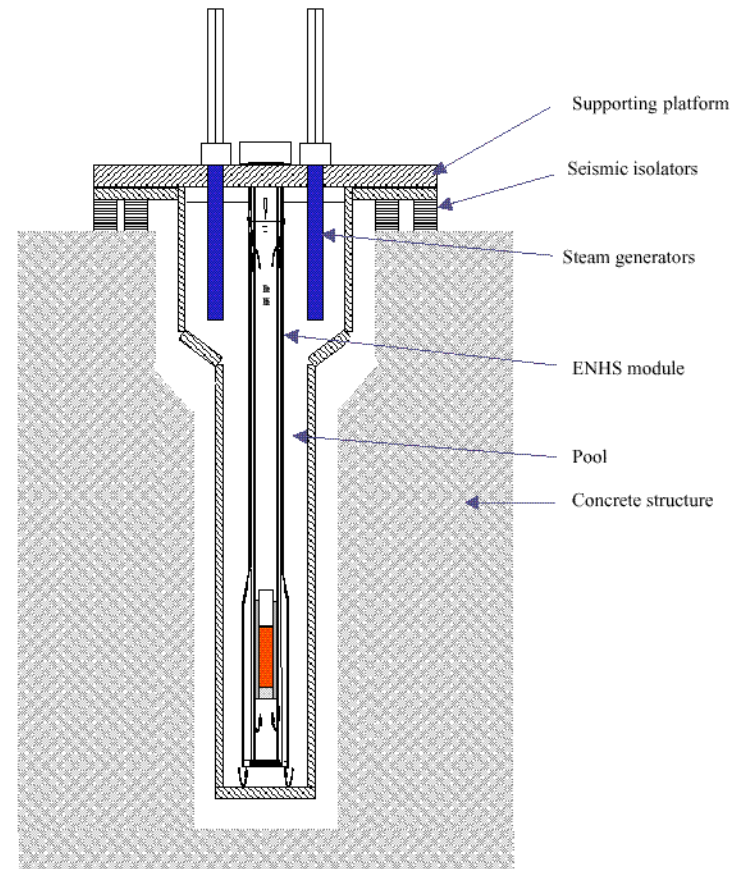
**Recently developed
magnetic turbine
bearings**



**10 MWe PBMR at
Tsinghua University, PRC
First criticality Dec. 2000**

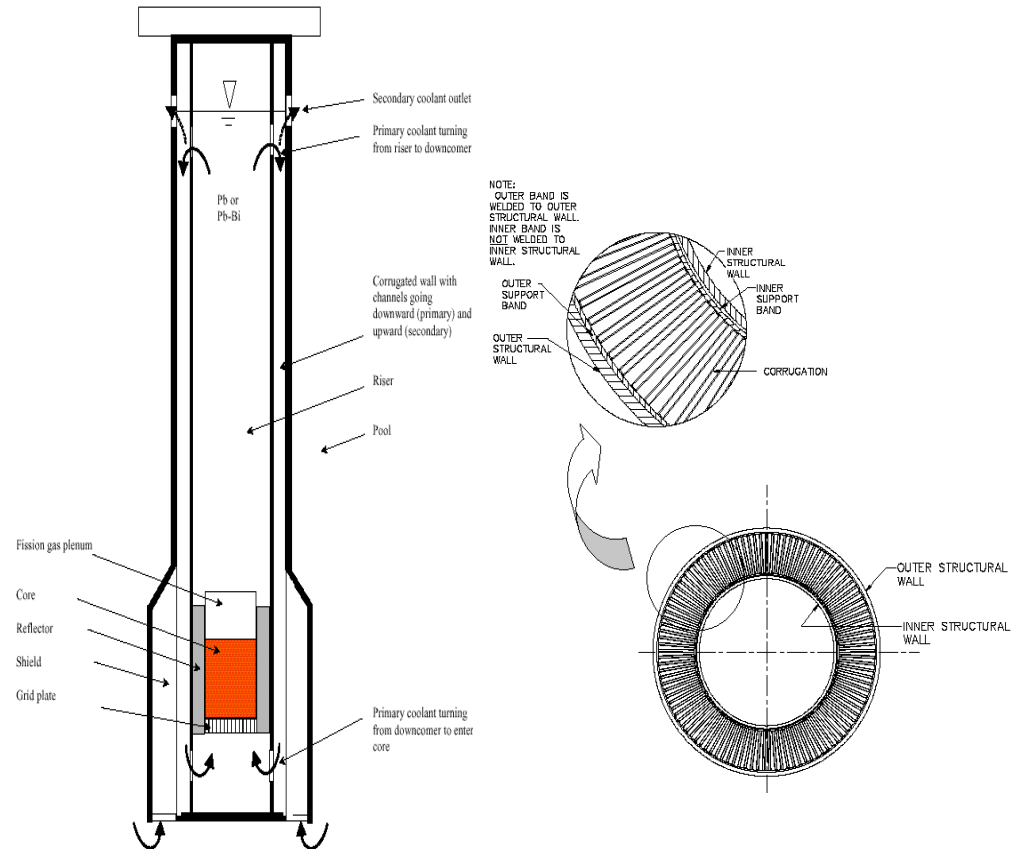
ENCAPSULATED NUCLEAR HEAT SOURCE (ENHS)

- **NERI-99 with**
 - U of Cal – Berkeley**
 - Westinghouse**
 - LLNL**
- **Member of the Safe Transportable Autonomous**
- **Reactor (STAR) family of modular concepts**
- **125 MW_{th}, Pb-Bi cooled, fast spectrum**
- **Factory-fabricated, transportable,**
- **15 year refueling module**
- **Inserted in secondary Pb-Bi pool at clients site**
- **Natural circulation heat transport across module wall**
- **Semi-autonomous operation**
- **Potential marketable in developing countries with developing grids**
- **shipped from factory in frozen Pb-Bi**
- **Used module returned to factory**
- **Passive safety, Passive decay heat removal**
- **Passive Load Follow**



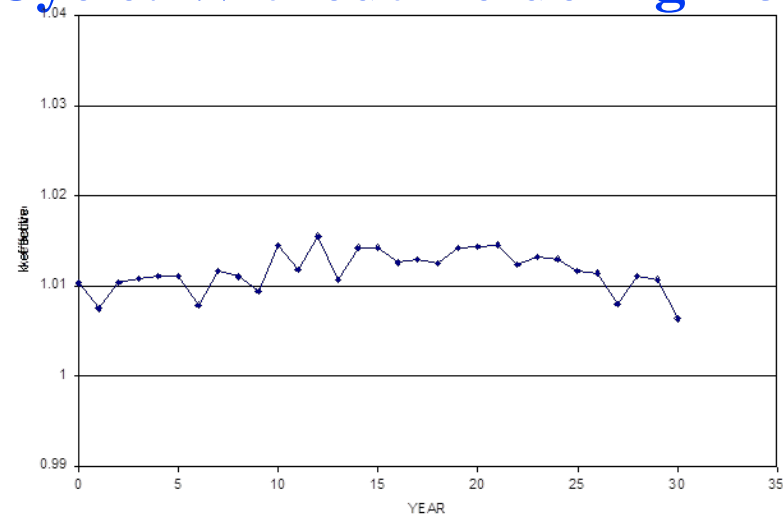
We have developed new fission core designs that can burn long-lived waste at the same rate it is created

- Based on Russian lead-bismuth coolant technology
- Highly efficient use of neutrons prevents accumulation of long-lived heavy elements
- Makeup fuel can be depleted uranium
- Decay heat removal by simple, passive natural circulation



UCBNE is now contributing key elements to the Generation IV Reactor Roadmap to be completed in 2002

Life-Cycle: Without Refueling > 30 years!



$k_{\text{effective}}$

10 region
1 region

Generation IV Tehnology Goals

- Gen IV will provide sustainable energy generation that meets clean air objectives and promotes long-term availability of systems and effective fuel utilization for worldwide energy production.
- Gen IV will 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.
- Gen IV will increase the assurance that they are a very unattractive and least desirable route for diversion or theft of weapons-usable materials.
- Gen IV will excel in safety and reliability with very low likelihood and degree of reactor damage.
- Gen IV will have a clear life-cycle cost advantage over other energy sources.