Integral Fast Reactor
A Next-Generation Reactor Concept

Panel on Future of Nuclear

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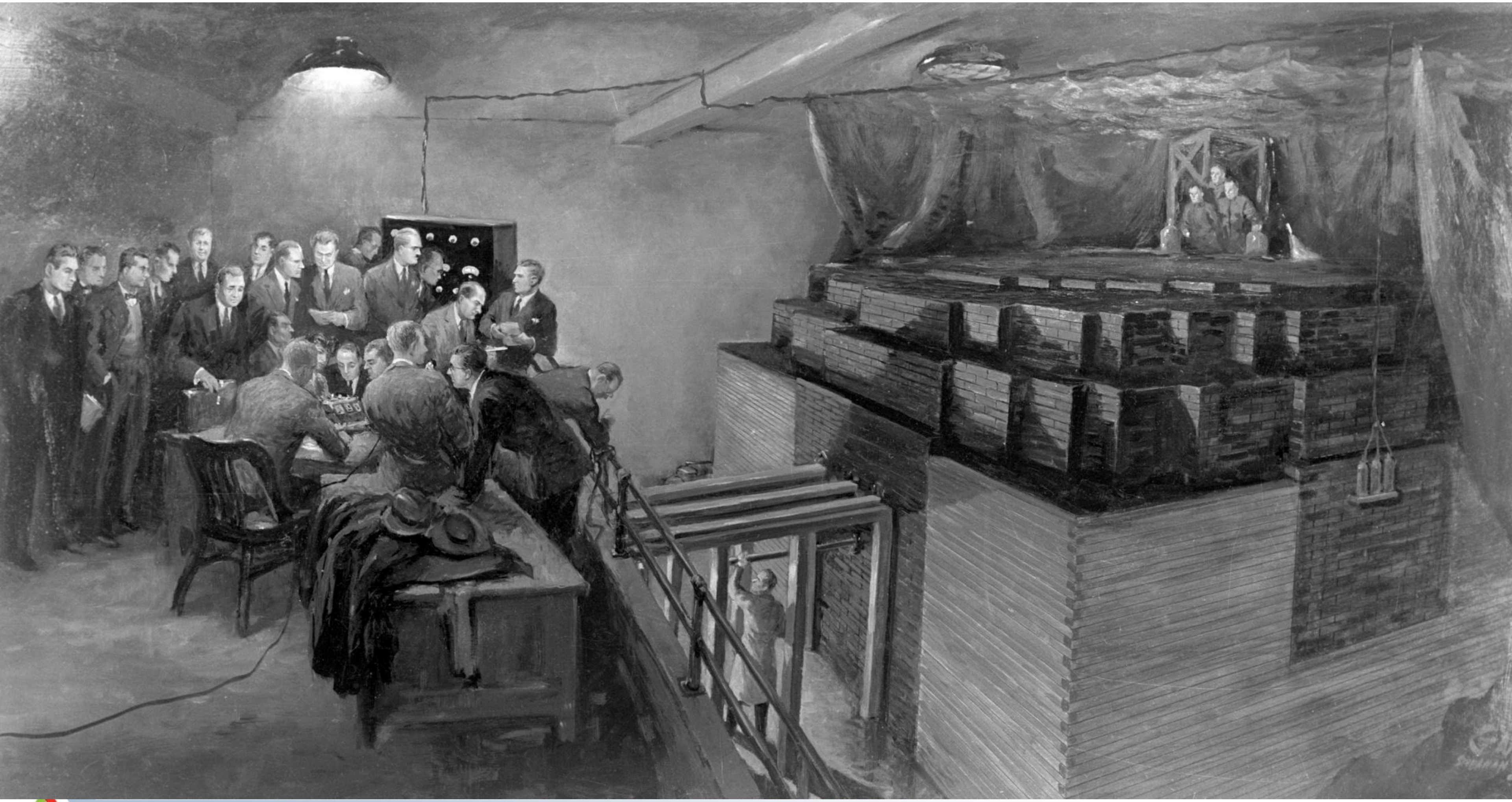
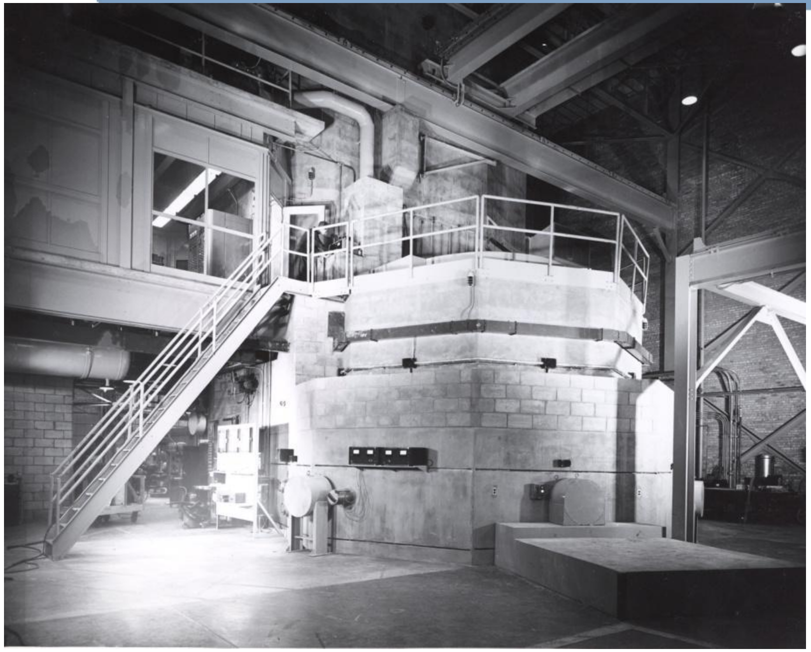
Enrico Fermi team achieved controlled chain reaction on December 2, 1942 (Chicago Pile-1, the world's first reactor)



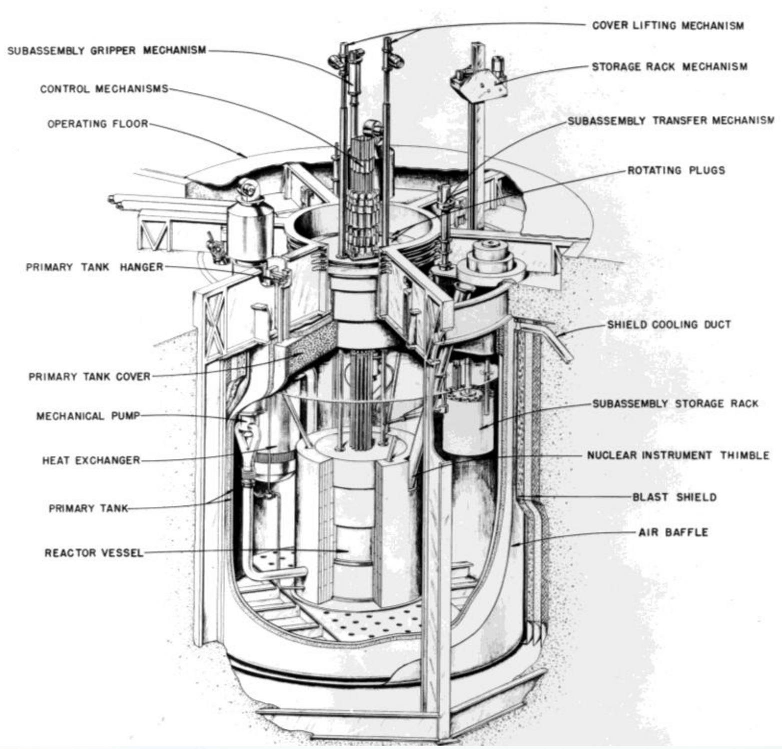
Experimental Breeder Reactor -I

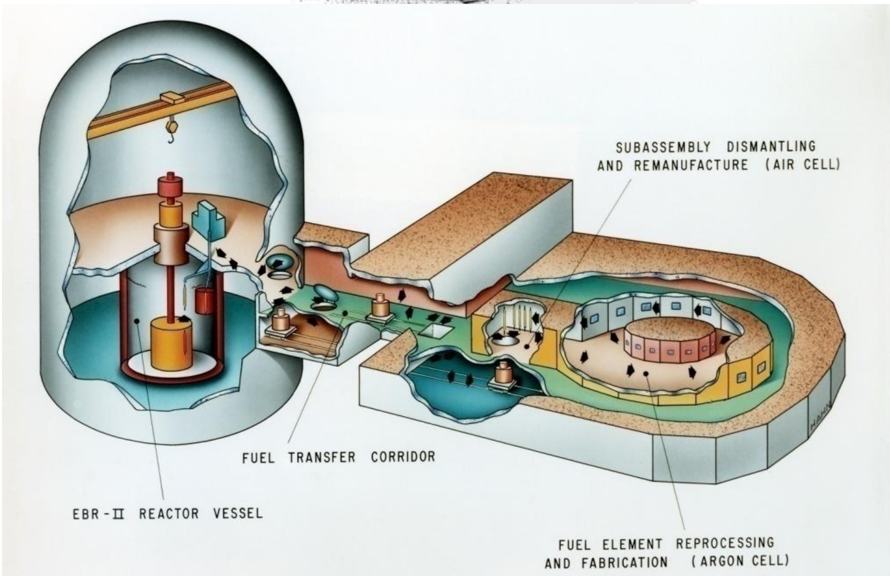
- CP-1 was reassembled as CP-2 at Argonne forest
- CP-3 was a heavy water reactor
- Fermi proposed fast reactor concept in 1944.
- CP-4 was a fast breeder reactor, renamed Experimental Breeder Reactor-I (EBR-I) and constructed at NRTS in Idaho (ANL-West, later INL)
- EBR-I produced the first electricity from nuclear in 1951.



Experimental Breeder Reactor-II

- The first pool-type SFR started operation in 1964.
- Demonstrated recycle based on melt-refining from 1964-69: ~30,000 irradiated fuel pins were recycled with average turnaround time of 2 months from discharge to reload into the reactor.
- Successfully operated over 30 years: no steam generator tube leak, reliability of sodium components due to compatibility with sodium, etc.





Worldwide Sodium-Cooled Fast Reactor Experience

Country	Reactor	MWth/Mwe	Operations
U.S.	EBR-I EBR-II Fermi-1 FFTF	1/0.2 62.5/20 200/61 400	1951-63 1964-94 1965-72 1980-92
Russia	BR-5/10 BOR-60 BN-350 BN-600	8 60/12 1000/150 1470/600	1958-02 1969- 1973-99 1980-
France	Rapsodie Phenix SuperPhenix	40 563/250 3000/1240	1967-83 1974-09 1985-97
Japan	Joyo Monju	140 714/300	1978- 1993-
UK	DFR PFR	72/15 600/270	1963-77 1976-94
Germany	KNK-II	58/21	1972-91
India	FBTR	42.5/12	1985-
China	CEFR	65/20	2010-

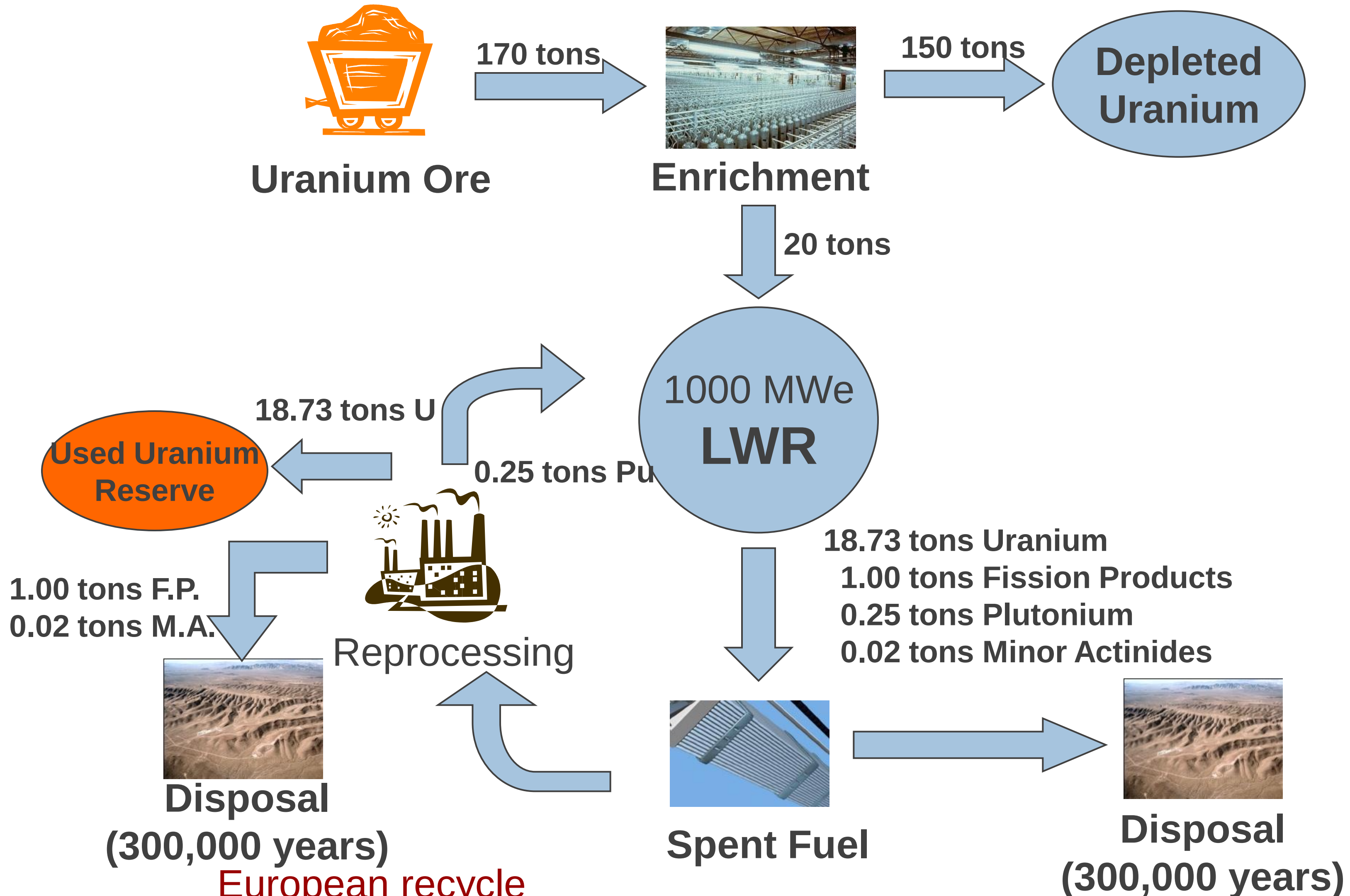
Status of Fast Reactors in the U.S.

- In the late 1970s, the construction of a 375 MWe commercial prototype, Clinch River Breeder Reactor (CRBR) was in progress.
- The CRBR project was cancelled following the President Carter’s policy announcement (actual cancellation in 1983).
- With the cancellation of the CRBR project, the entire fast reactor technology development program was in danger being phased out gradually.
- Argonne launched the Integral Fast Reactor (IFR) initiative in 1984 as a new fast reactor technology direction for the future in order to overcome the barriers.

Technical Rationale for the IFR

- Revolutionary improvements as a next generation nuclear concept:
  - Inexhaustible Energy Supply
  - Inherent Passive Safety
  - Long-term Waste Management Solution
  - Proliferation-Resistance
  - Economic Fuel Cycle Closure
- Metal fuel and pyroprocessing are key to achieving these revolutionary improvements.
- Implications on LWR spent fuel management

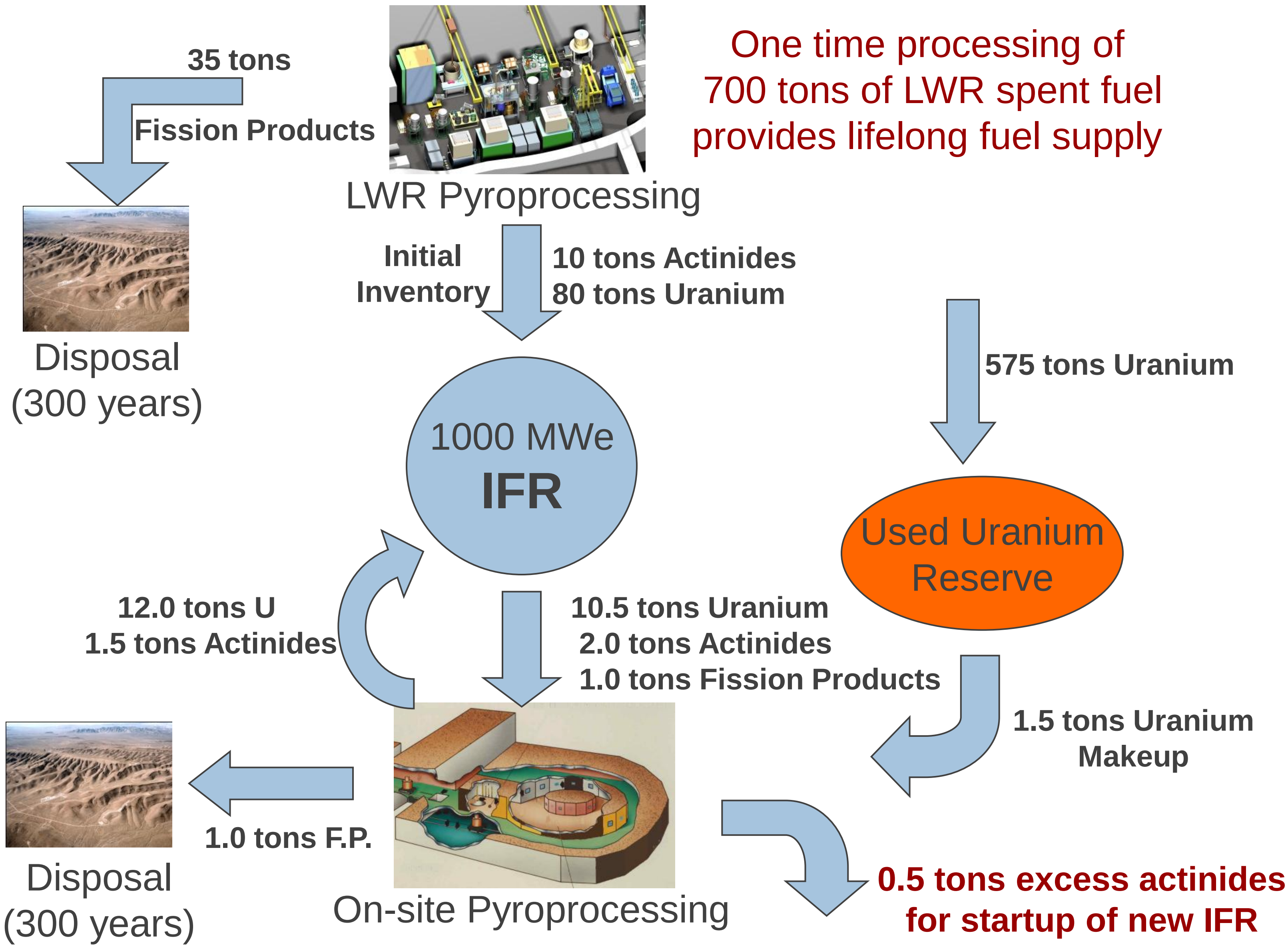
Uranium utilization is <1% in LWR



European recycle
- Saves 15% uranium
- But no reduction in waste life

Direct disposal is the current U.S. policy

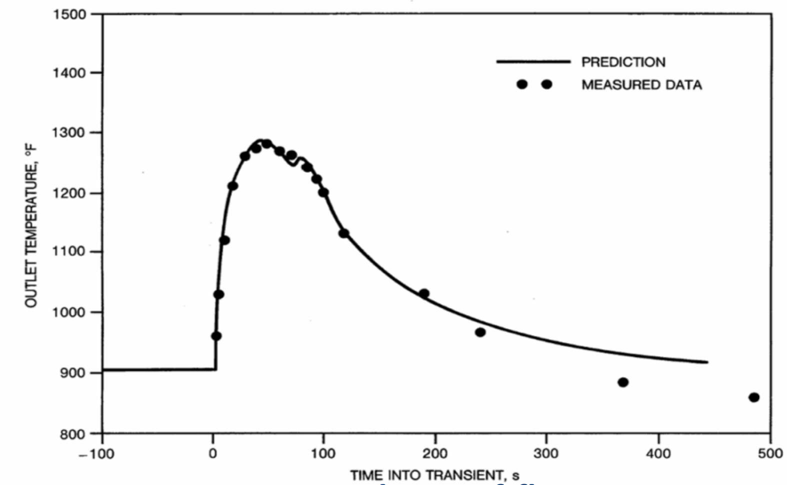
IFR is self-sufficient after initial startup



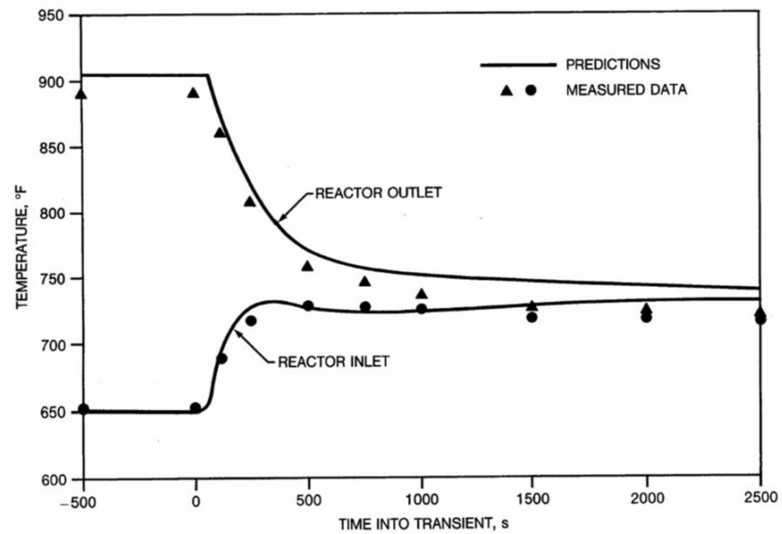
Inherent Safety Is Unique in IFR

Inherent passive safety features were demonstrated in landmark tests conducted in April 1986 on EBR-II. The reactor shut itself down without operator actions nor safety systems for two most severe accident initiators:

- Unprotected loss-of-flow at full power
- Unprotected loss-of-heat-sink at full power

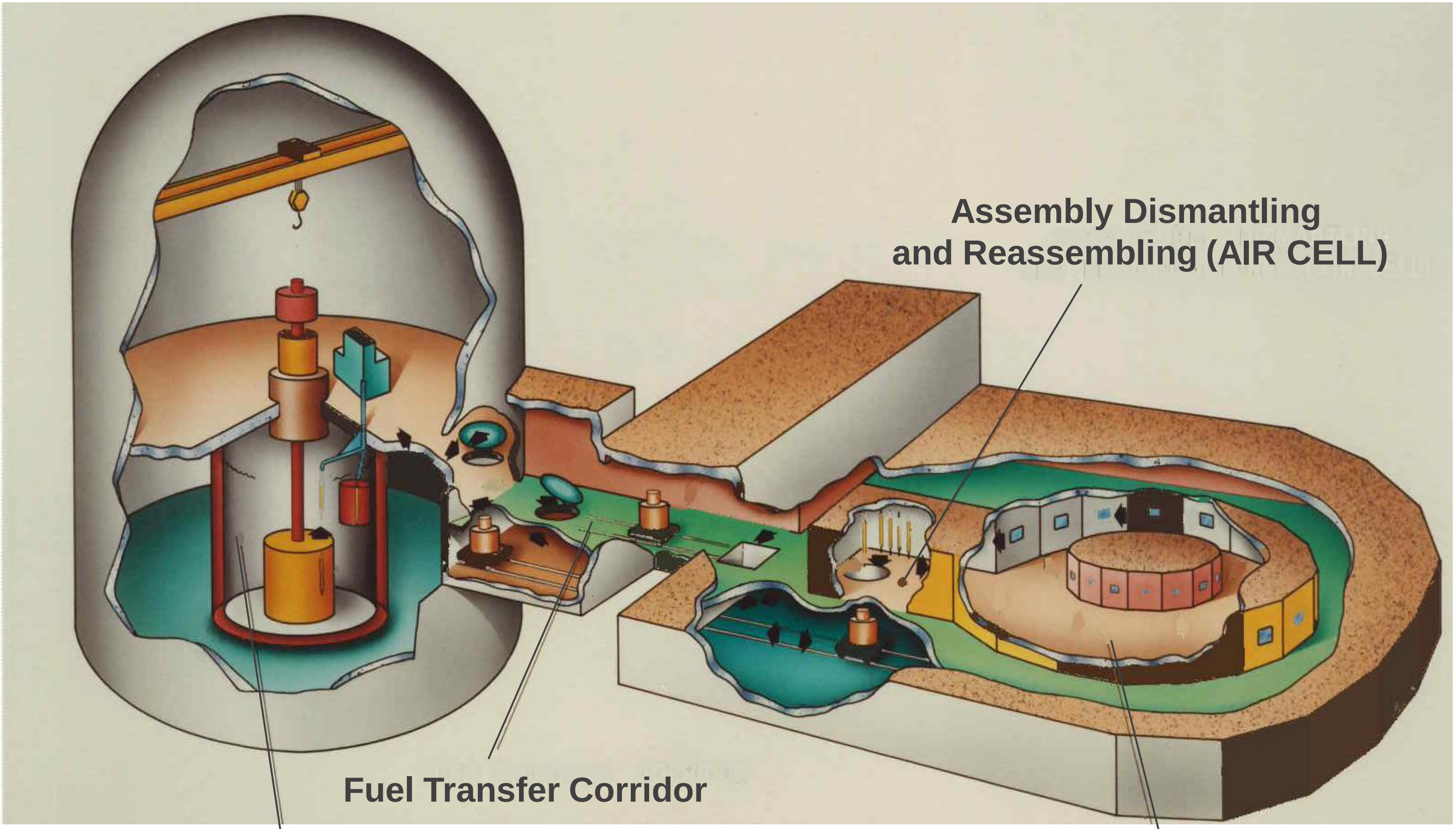


Unprotected Loss-of-flow Test

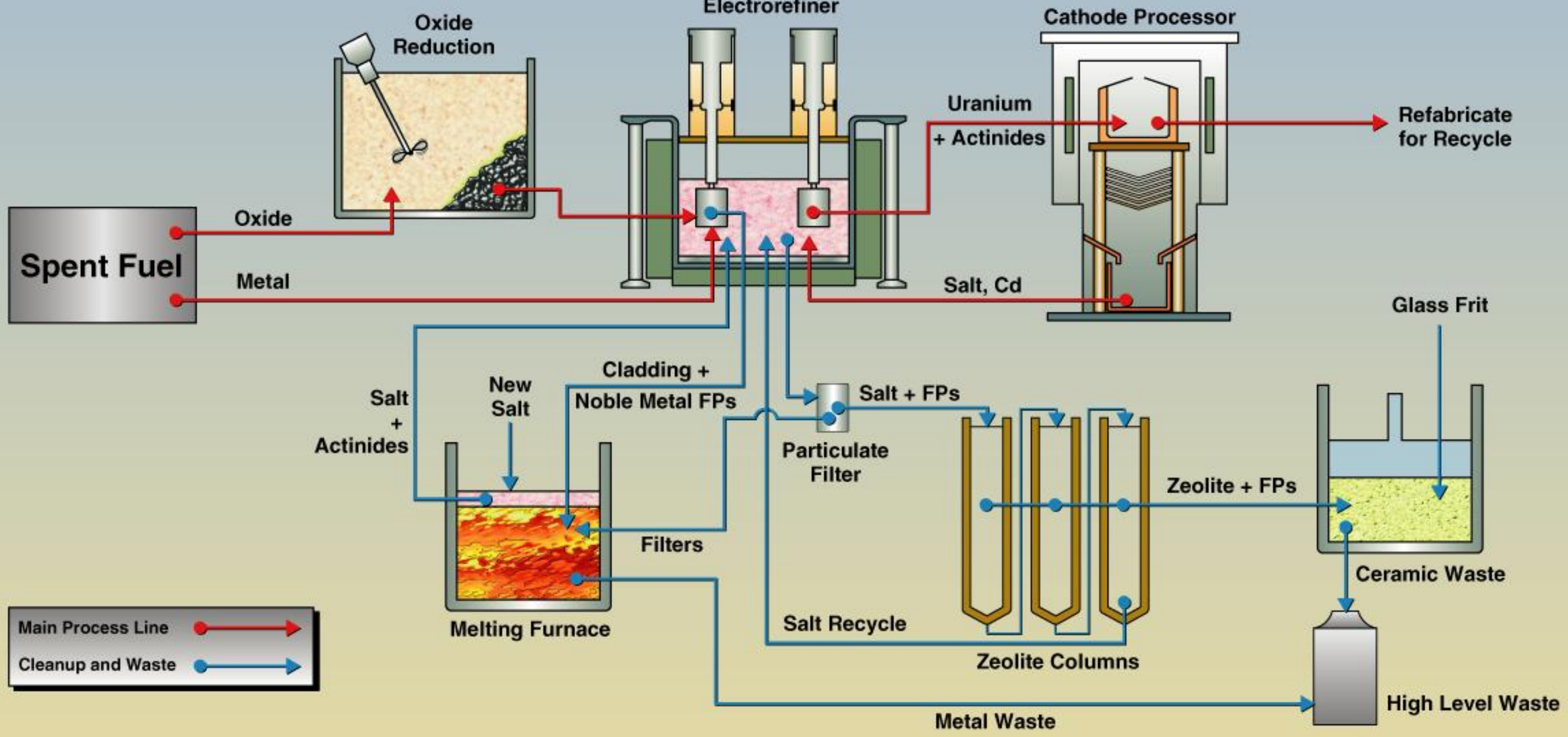


Unprotected Loss-of-heat-sink Test

Pyroprocessing was used to demonstrate the EBR-II fuel cycle closure during 1964-69



Pyroprocessing Flowsheet



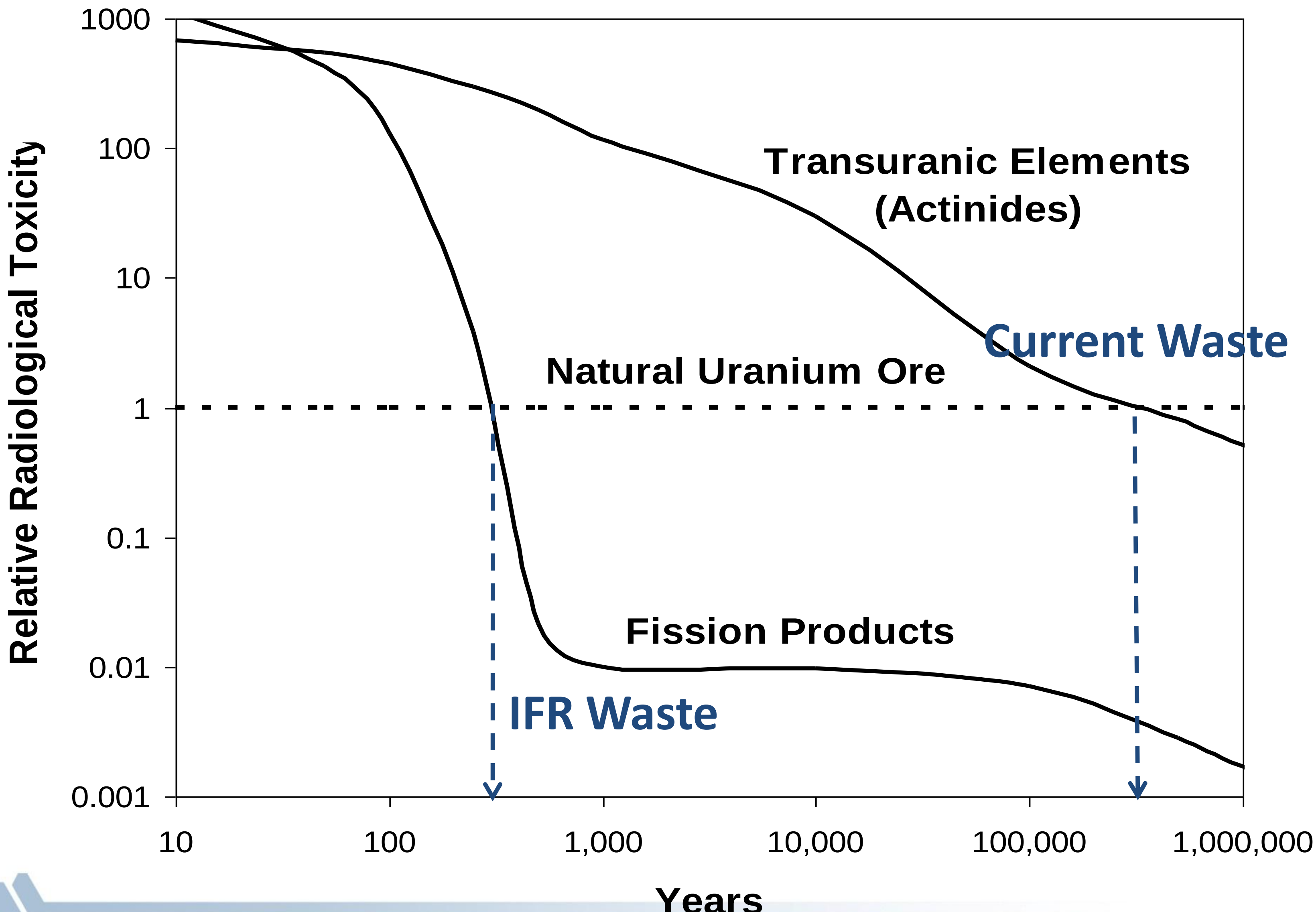
Capital Cost Comparison ($million)
Fuel Cycle Facility for 1400 MWe Fast Reactor

	Pyroprocessing	Aqueous Reprocessing
Size and Commodities		
Building Volume, ft3	852,500	5,314,000
Volume of Process Cells, ft3	41,260	424,300
High Density Concrete, cy	133	3,000
Normal Density Concrete, cy	7,970	35-40,000
Capital Cost, $million		
Facility and Construction	65.2	186.0
Equipment Systems	31.0	311.0
Contingencies	24.0	124.2
Total	120.2	621.2

Pyroprocessing's Intrinsic Proliferation-Resistant Characteristics: Weapons Usability Comparison

	Weapon Grade Pu	Reactor Grade Pu	IFR Grade Actinide
Production	Low burnup PUREX	High burnup PUREX	Fast reactor Pyroprocess
Composition	Pure Pu 94% Pu-239	Pure Pu 65% Pu-fissile	Pu + MA + U 50% Pu-fissile
Thermal power w/kg	2 - 3	5 - 10	80 - 100
Spontaneous neutrons, n/s/g	60	200	300,000
Gamma radiation r/hr at ½ m	0.2	0.2	200

Effective lifetime of nuclear waste can be reduced from ~300,000 to ~300 years



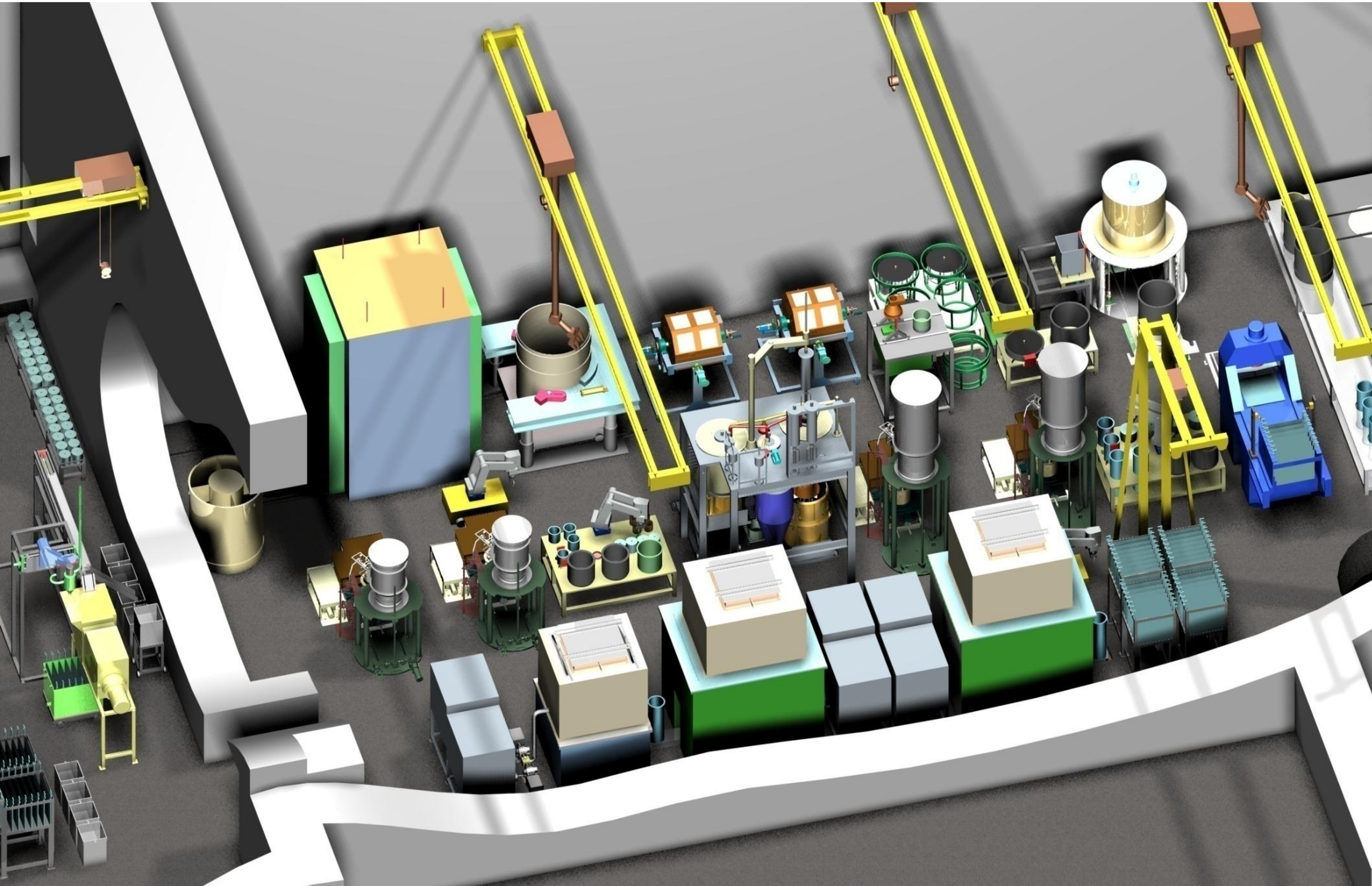
Waste Management Implications

- If actinides are removed from the waste stream and burned in the reactor, then the effective lifetime of nuclear waste is reduced from ~300,000 years to ~300 years.
- The task for repository siting will be easier and also the task of assuring the integrity of the waste packages, which will help the public acceptance.
- The lack of long term decay heat will also allow more wastes to be disposed in a given space.
- Therefore, the long-term energy potential combined with the near-term waste management solution mandate an early deployment of fast reactors.
- The next question then is whether pyroprocessing can be applied to LWR spent fuel.

Pyroprocessing for LWR Spent Fuel

- Electrorefining has been demonstrated for fast reactor metal spent fuels.
- For LWR spent fuel application, oxide-to-metal reduction front-end step is required:
  - Electrolytic reduction process
- For economic viability, the electrorefining batch size and throughput rate has to be increased: this should be straightforward with planar electrode concept.
- A preconceptual design for a 100 T/yr facility has been developed along with detailed flowsheet, equipment concepts and operational process models.

Pre-conceptual design of a pilot-scale (100 T/yr) LWR Pyroprocessing Facility



Capital Cost for LWR Pyroprocessing Facility

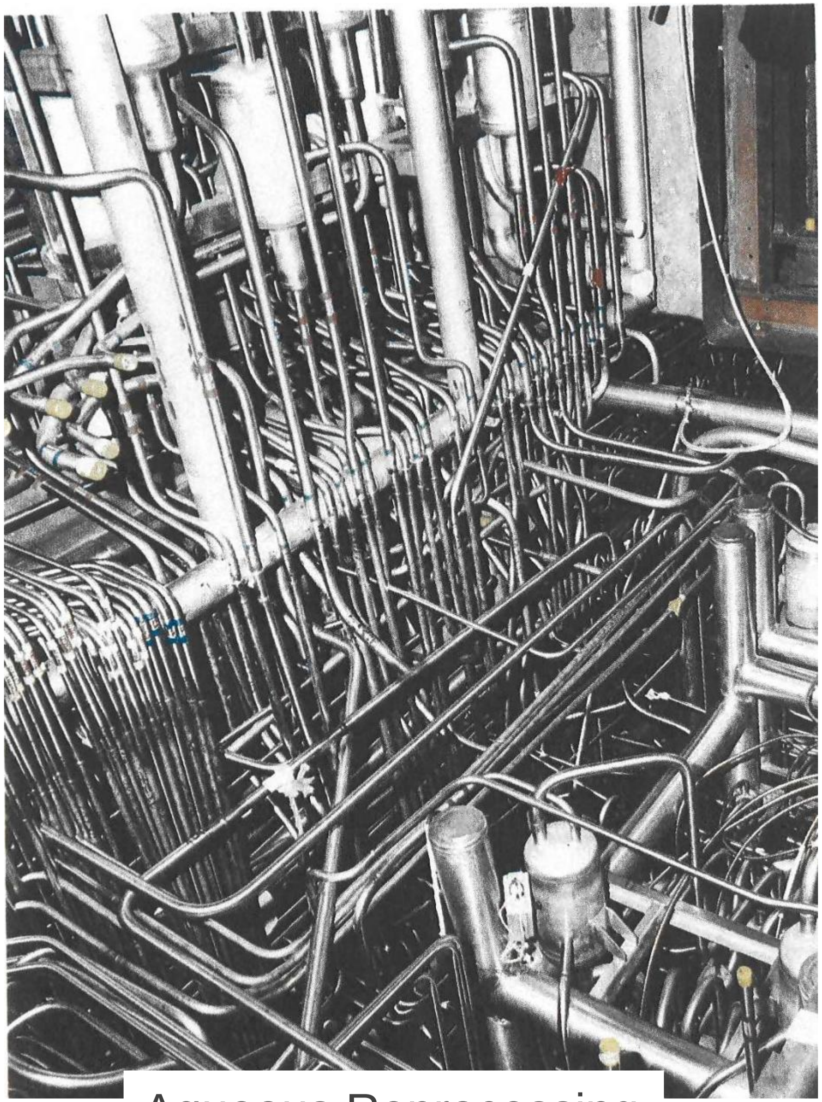
- The capital cost for the 100 ton/yr LWR pyroprocessing is estimated at:

Engineering	150
Construction	130
Equipment systems	120
Contingencies	100
Total	$500 million

- Even if the equipment systems are duplicated without any further scaleup, a commercial scale (800 T/yr) would cost about $2.5 billion, which is an order of magnitude less than equivalent aqueous reprocessing plants.
- The above is a very rough estimate based on experiences of the EBR-II FCF refurbishment (<$50 million) and the Fuel Manufacturing Facility ($4 million).

Pyroprocessing provides economic fuel cycle closure and intrinsic proliferation resistance

Pyroprocessing



Aqueous Reprocessing

Renewed interests in Fast Reactors

- After 20 years of hiatus, the interest in fast reactors has been renewed along with the nuclear renaissance.
- India has successfully operated FBTR since 80s and the 500 MWe DFBR is expected to be online next year. Subsequently, they plan to construct 4 more MWe units by 2020.
- China has constructed CEFR, which achieved the initial criticality on July 21, 2010. They have a firm plan to construct a follow-on 1,000 MWe fast reactor or two BN-800 plants in collaboration with Russia.
- Russia has resumed the construction of BN-800 to be online ~2014 and have plans for BN-1200 follow-on plants.
- Both China and India envision rapidly growing demand for nuclear and consider fast breeder reactors to be essential part of their future energy mix.