The Integral Fast Reactor
PLENTIFUL
ENERGY
The Story of the Integral Fast Reactor
The complex history of a simple reactor technology, with emphasis on its scientific basis for non-specialists

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www.thesciencecouncil.com
Positive proof of global warming.
## Worldwide Sodium-Cooled Fast Reactor Experience

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

- 170 tons Uranium Ore
- 150 tons Depleted Uranium
- 20 tons enrichment

Used Uranium Reserve:
- 18.73 tons U
- 0.25 tons Pu
- 1.00 tons F.P.
- 0.02 tons M.A.

1000 MWe LWR:
- 18.73 tons Uranium
- 1.00 tons Fission Products
- 0.25 tons Plutonium
- 0.02 tons Minor Actinides

Disposal (300,000 years):
- Direct disposal is the current U.S. policy
- European recycle
  - Saves 15% uranium
  - But no reduction in waste life
IFR is self-sufficient after initial startup

One time processing of 700 tons of LWR spent fuel provides lifelong fuel supply

LWR Pyroprocessing

Initial Inventory
10 tons Actinides
80 tons Uranium

1000 MWe IFR

LWR Pyroprocessing

35 tons
Fission Products

Disposal (300 years)

12.0 tons U
1.5 tons Actinides

On-site Pyroprocessing

1.0 tons F.P.

Disposal (300 years)

575 tons Uranium

Used Uranium Reserve

1.5 tons Uranium Makeup

0.5 tons excess actinides for startup of new IFR
THE ESSENTIALS OF AN ACTINIDE-CONSUMING FUEL CYCLE

1000 MWe power plant

U-238 in 1 ton per year

Energy out

FP out 1 ton per year

In the power plant:
- A fast reactor
- A facility to extract the fission products and make new fuel elements

NO LOOSE PLUTONIUM -- ANYWHERE!!

NO MORE ENRICHMENT OF URANIUM – EVER!!
Liquid Metal cooled Fast Breeder Reactors (LMFBR) "Pool" Design

- Control rods
- Flow baffle
- Coolant level
- Fissile Core
- Reactor pool pump
- Biological shielding
- Liquid metal coolant
- Heat exchanger
- Steam generator

- Water
- Steam

- Reactor pool (primary coolant)
- Intermediate loop
- Power-generation loop
Figure 6-1. Schematic of metal fuel
Assembly Dismantling and Reassembling (AIR CELL)

Fuel Pin Pyroprocessing and Refabrication (ARGON CELL)

Reactor Vessel

Fuel Transfer Corridor
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.
USED LWR FUEL

All of it is now treated as waste, but it’s not

URANIUM 93.8%

The REAL waste

OTHER TRANSURANICS 0.2%

FISSION PRODUCTS 5.0%

PLUTONIUM 1.0%

With this portion consumed (in fast reactors), dangerous activity is gone in 300 years
100 tons

Spent Nuclear Fuel (SNF) (Store 300,000 Years)

Or...

100 Ton/year Pyroprocessing Plant

- 5 TON Fission Products (Store 300 Years)
- 93 TON Reprocessed Uranium (Future Fuel Source)
- 2 TON Metal Fuel Ingots ("Seed" Fuel for Fast Reactors)
Pyroprocessing provides economic fuel cycle closure and intrinsic proliferation resistance.
Radiological Toxicity of LWR Spent Fuel

Relative Radiological Toxicity -

Transuranic Elements (Actinides)

Natural Uranium Ore

Fission Products

Current Waste

IFR Waste

Years

10

100

1,000

10,000

100,000

1,000,000

Relative Radiological Toxicity -

1000

100

10

1

0.1

0.01
Pyroprocessing’s Intrinsic Proliferation-Resistant Characteristics: Weapons Usability Comparison

<table>
<thead>
<tr>
<th></th>
<th>Weapon Grade Pu</th>
<th>Reactor Grade Pu</th>
<th>IFR Grade Actinide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>Low burnup PUREX</td>
<td>High burnup PUREX</td>
<td>Fast reactor Pyroprocess</td>
</tr>
<tr>
<td>Composition</td>
<td>Pure Pu 94% Pu-239</td>
<td>Pure Pu 65% Pu-fissile</td>
<td>Pu + MA + U 50% Pu-fissile</td>
</tr>
<tr>
<td>Thermal power w/kg</td>
<td>2 - 3</td>
<td>5 - 10</td>
<td>80 - 100</td>
</tr>
<tr>
<td>Spontaneous neutrons, n/s/g</td>
<td>60</td>
<td>200</td>
<td>300,000</td>
</tr>
<tr>
<td>Gamma radiation r/hr at ½ m</td>
<td>0.2</td>
<td>0.2</td>
<td>200</td>
</tr>
</tbody>
</table>
Capital Cost for LWR Pyroprocessing Facility

- The capital cost for the 100 ton/yr LWR pyroprocessing is estimated at:
  - Engineering: 100
  - Construction: 120
  - Equipment systems: 100
  - Contingencies: 80
  - Total: $400 million

- Even if the equipment systems are duplicated without any further scale-up, 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).
PRISM
During the 11 years between 1978 and 1989, electricity demand in the country about doubled, even as nuclear's share rocketed from 20% to 80%.