WE START WITH YES.

# PYROPROCESSING: A PRACTICAL SOLUTION TO SPENT FUEL MANAGEMENT

Pilot-scale Pyroprocessing Facility

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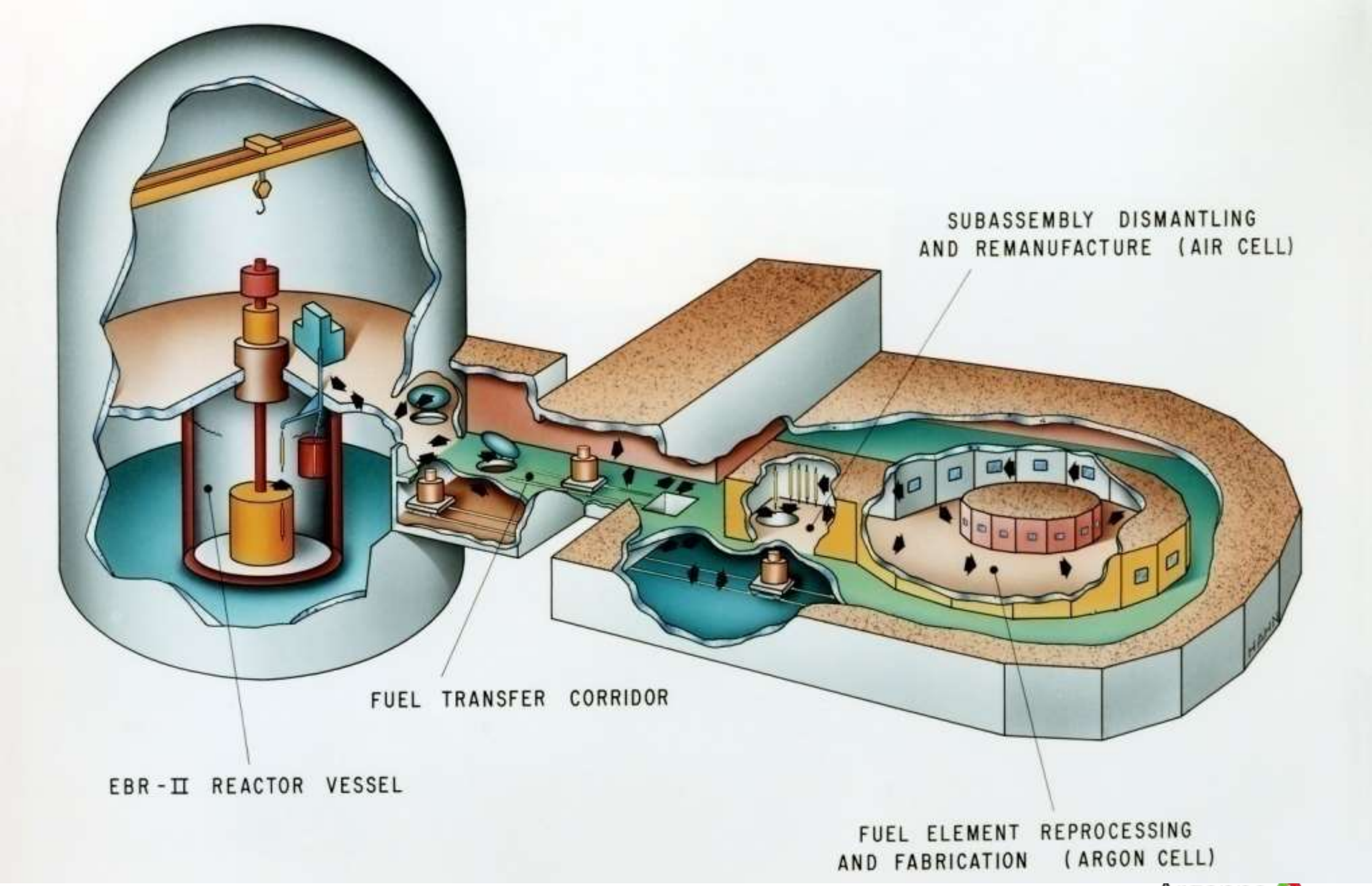
# NEAR-TERM IMPERATIVES

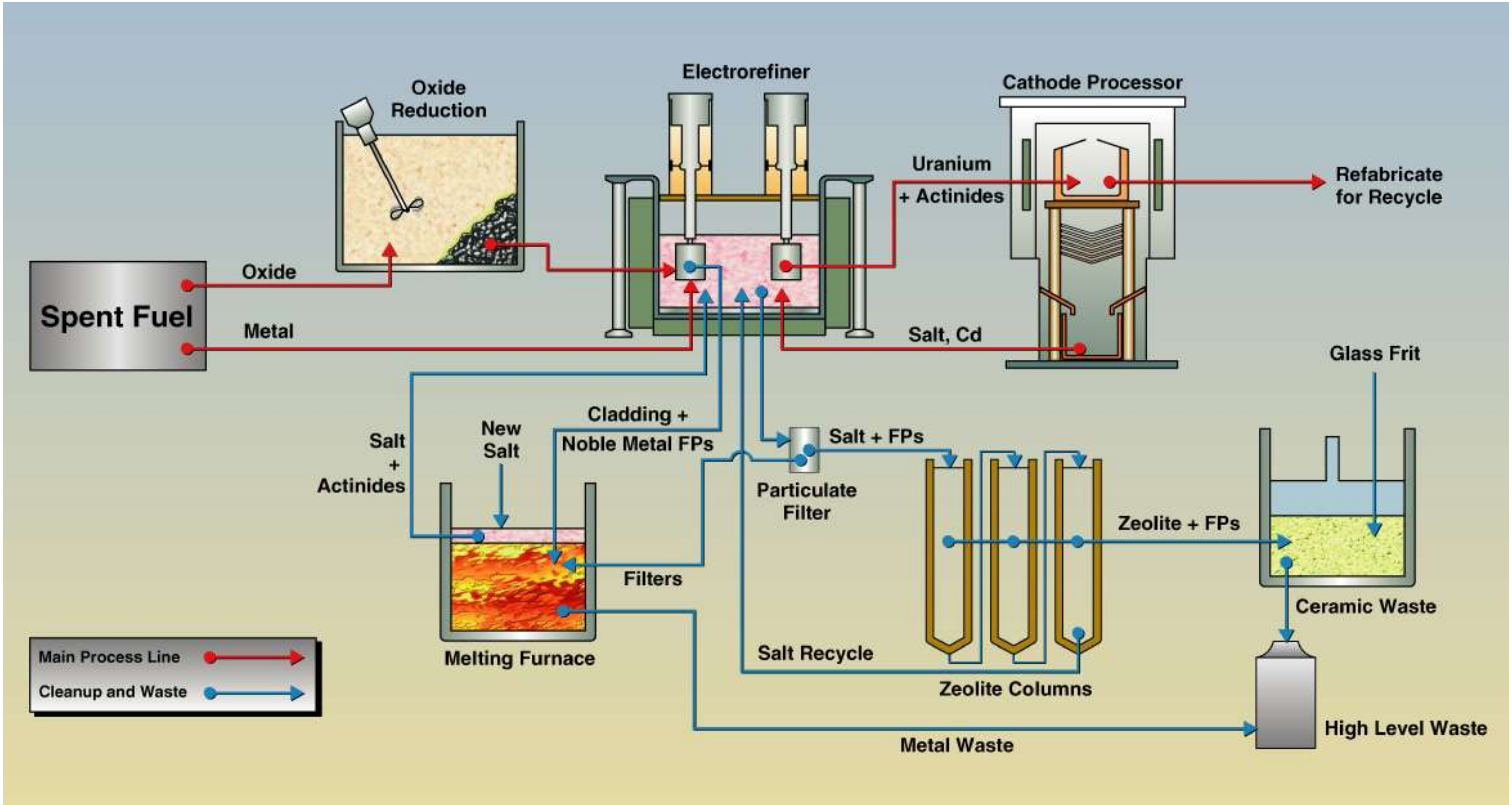
- The public views adequate nuclear waste management as a critical linchpin in further development of nuclear energy. Nuclear energy has been utilized over a half century without a definite solution to the back end of the fuel cycle. Examples of metaphors:
  - “Building a house without a toilet!”
  - “A plane taking off without its landing gear!”
- Pyroprocessing is by far the best technology option to solve the spent fuel management dilemma.
- Pyroprocessing also enables full utilization of uranium resources transitioning from the current once-through cycle to the full recycling in the next generation advanced reactors.

# EARLY HISTORY OF PYROPROCESSING

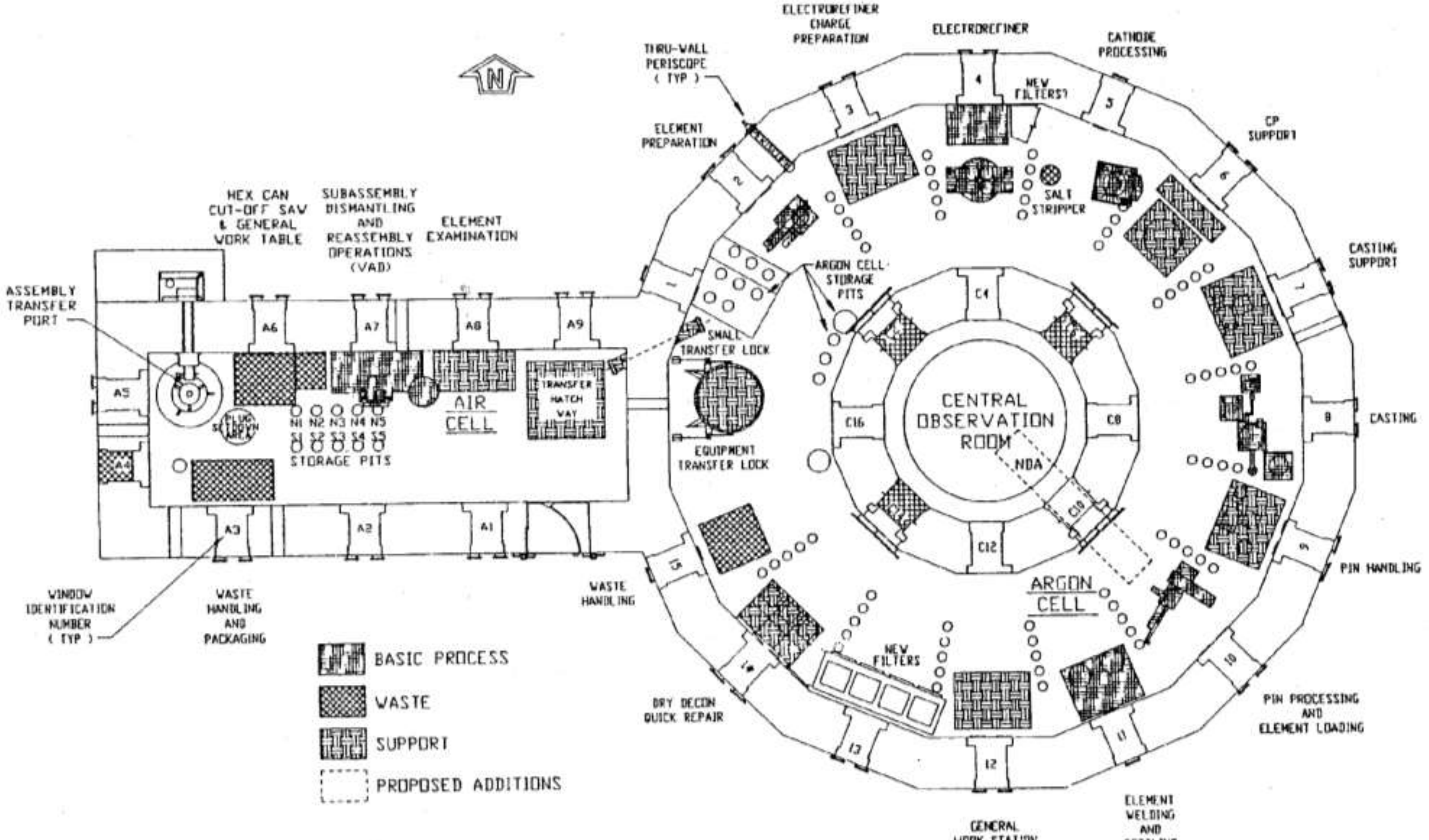
- Melt-refining based pyroprocessing was utilized to recycle 35,000 EBR-II fuel pins with typical turnaround time of 45 days up to 5 times during 1965-1969.



# PYROPROCESSING FLOWSHEET

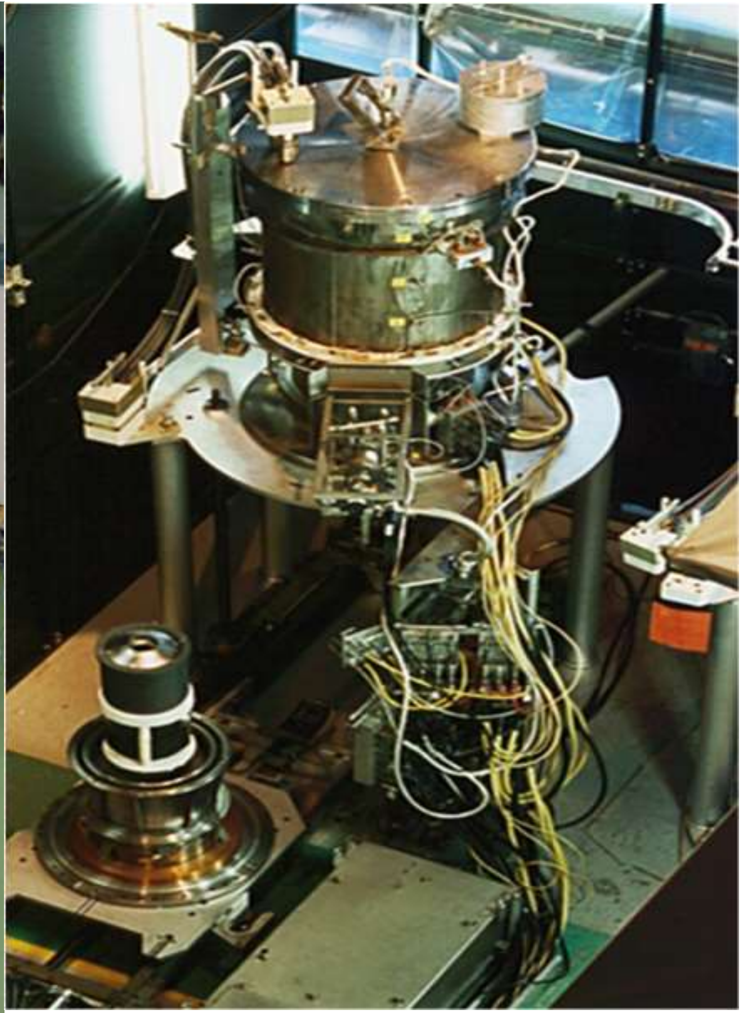


# EBR-II FCF REFURBISHED FOR ENGINEERING-SCALE DEMONSTRATION AS PART OF THE IFR PROGRAM



# ENGINEERING-SCALE EQUIPMENT DEMONSTRATED


Electrorefiner


Cathode Processor


Metal Waste Furnace

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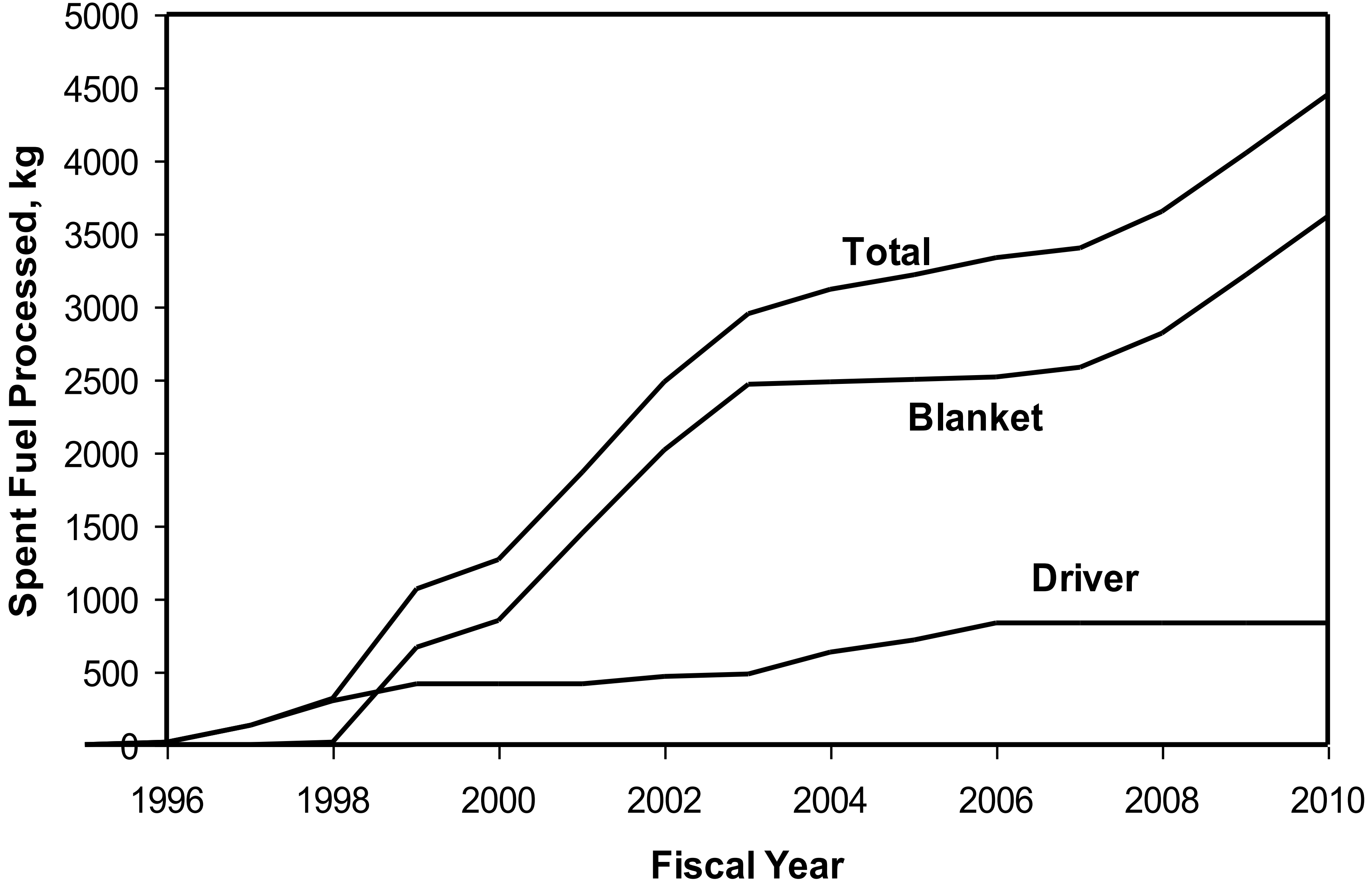
# ENGINEERING-SCALE PYROPROCESSING HAS BEEN SUCCESSFULLY DEMONSTRATED THROUGH EBR-II USED FUEL TREATMENT

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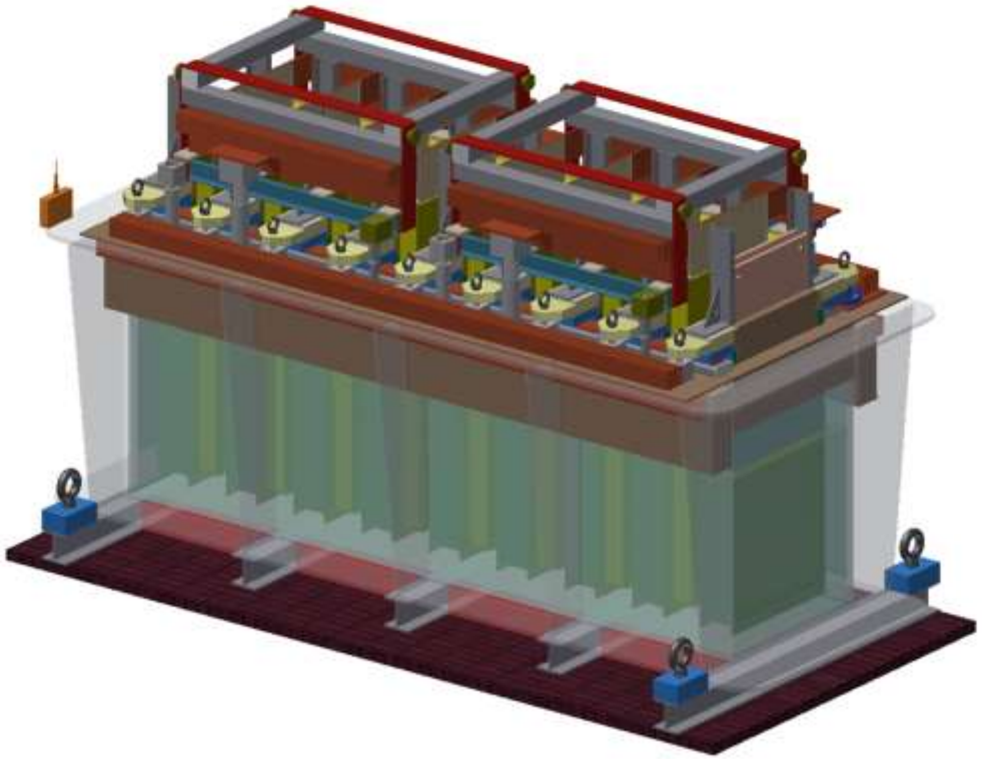
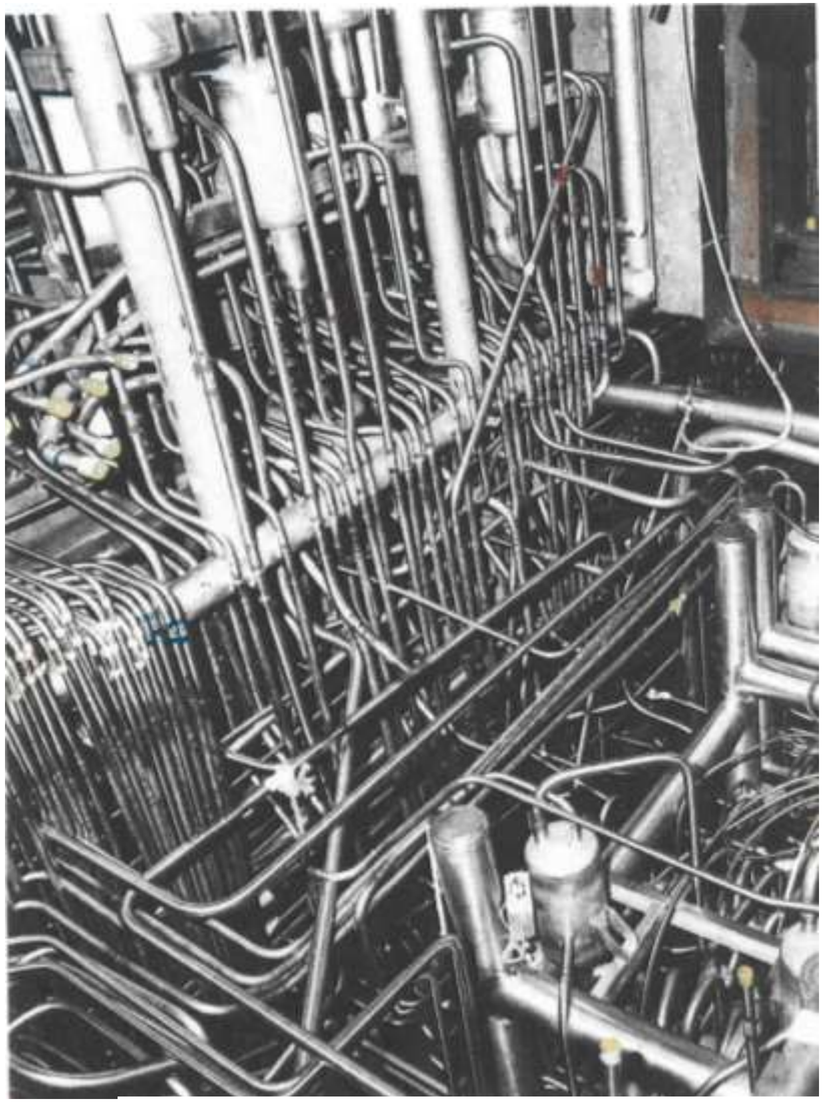
# PYROPROCESSING ATTRIBUTE 1: COMPACT FACILITY LEADING TO DRASTICALLY IMPROVED ECONOMICS

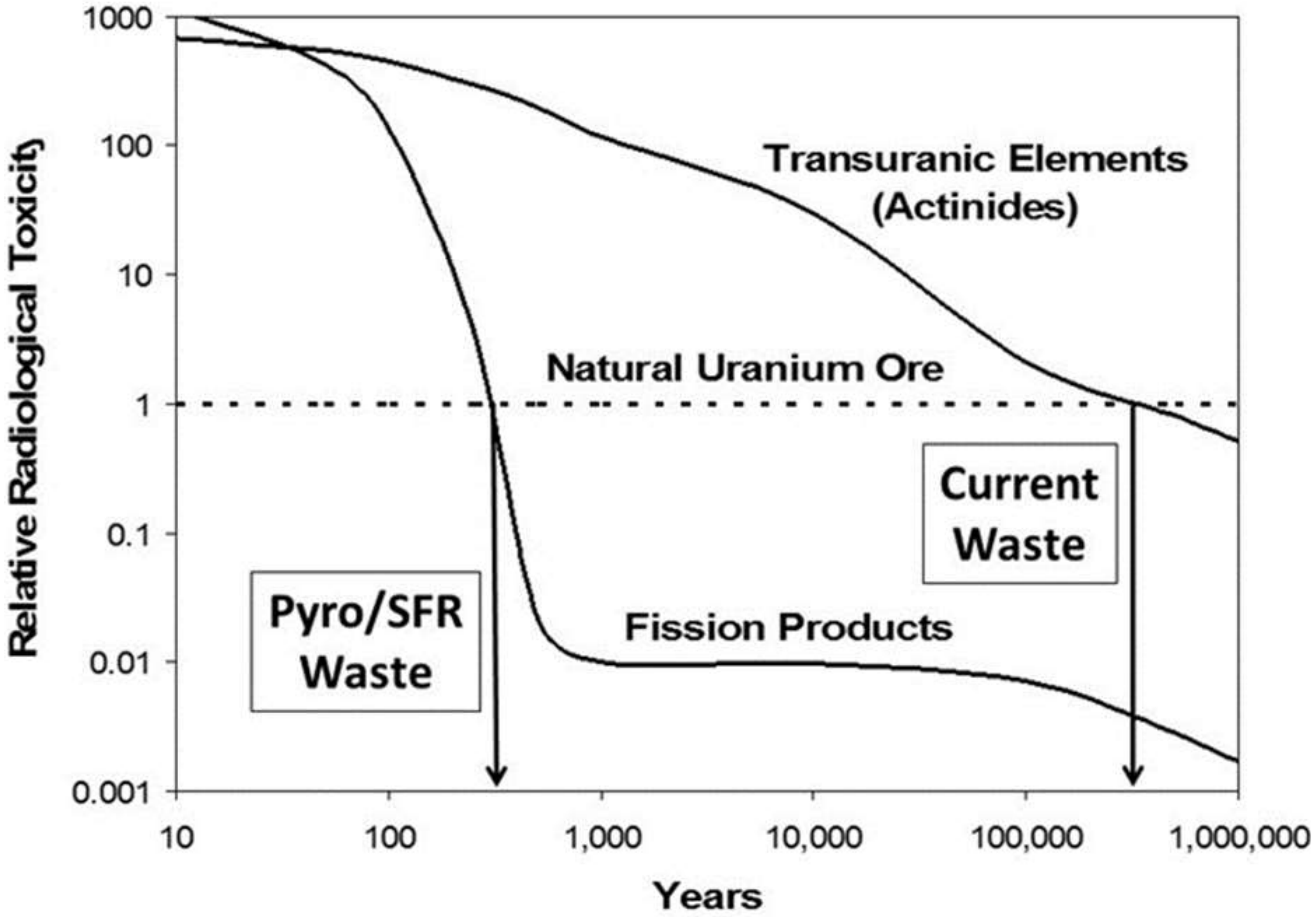


**Electrorefiner Pyroprocessing**



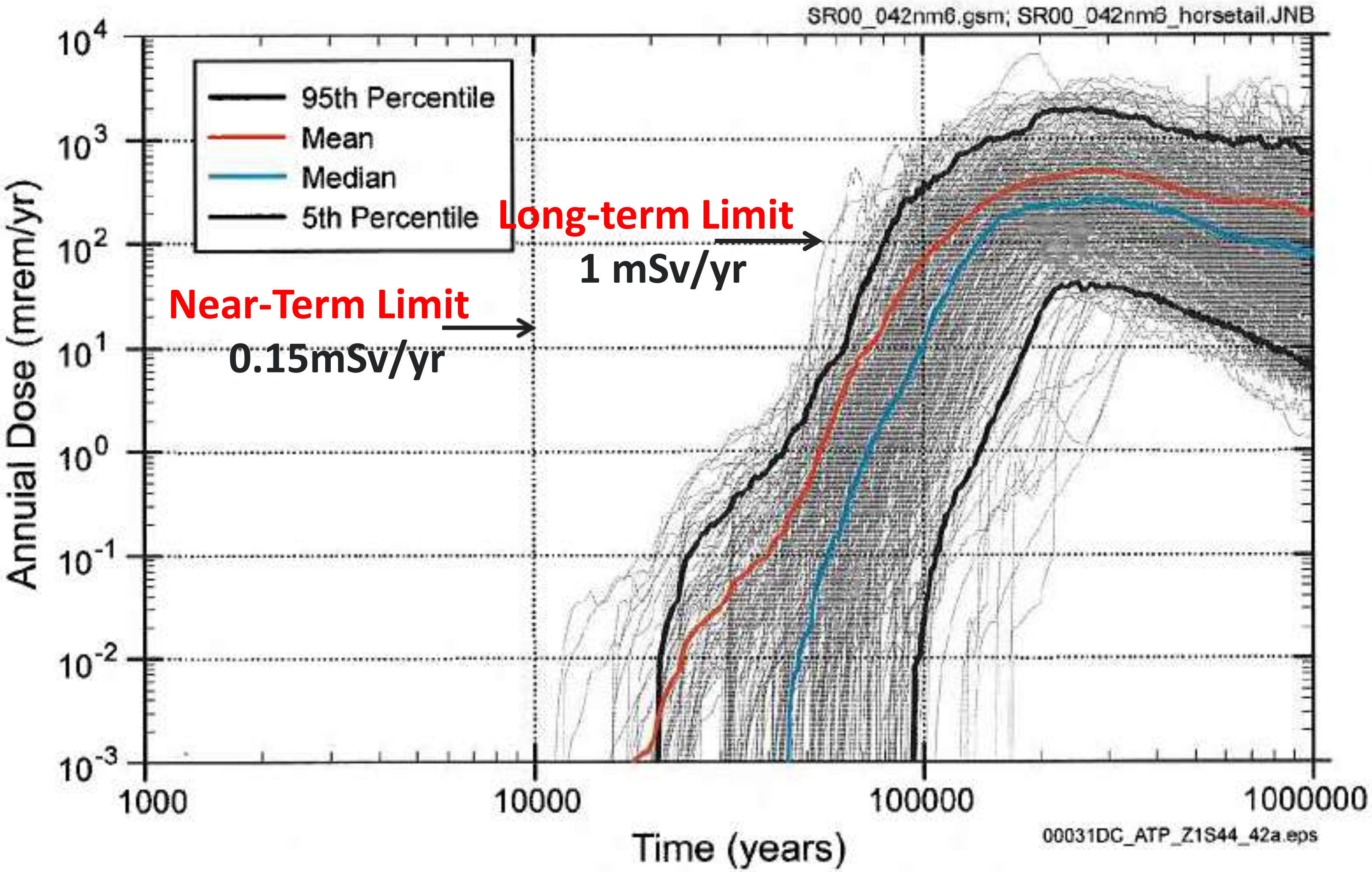
**Aqueous Reprocessing**

# PYROPROCESSING ATTRIBUTE 3: RADIOLOGICAL TOXICITY IS REDUCED DRASTICALLY WITH ACTINIDE REMOVAL



# REPOSITORY PERFORMANCE ASSESSMENT ILLUSTRATES IMPACT OF ACTINIDES

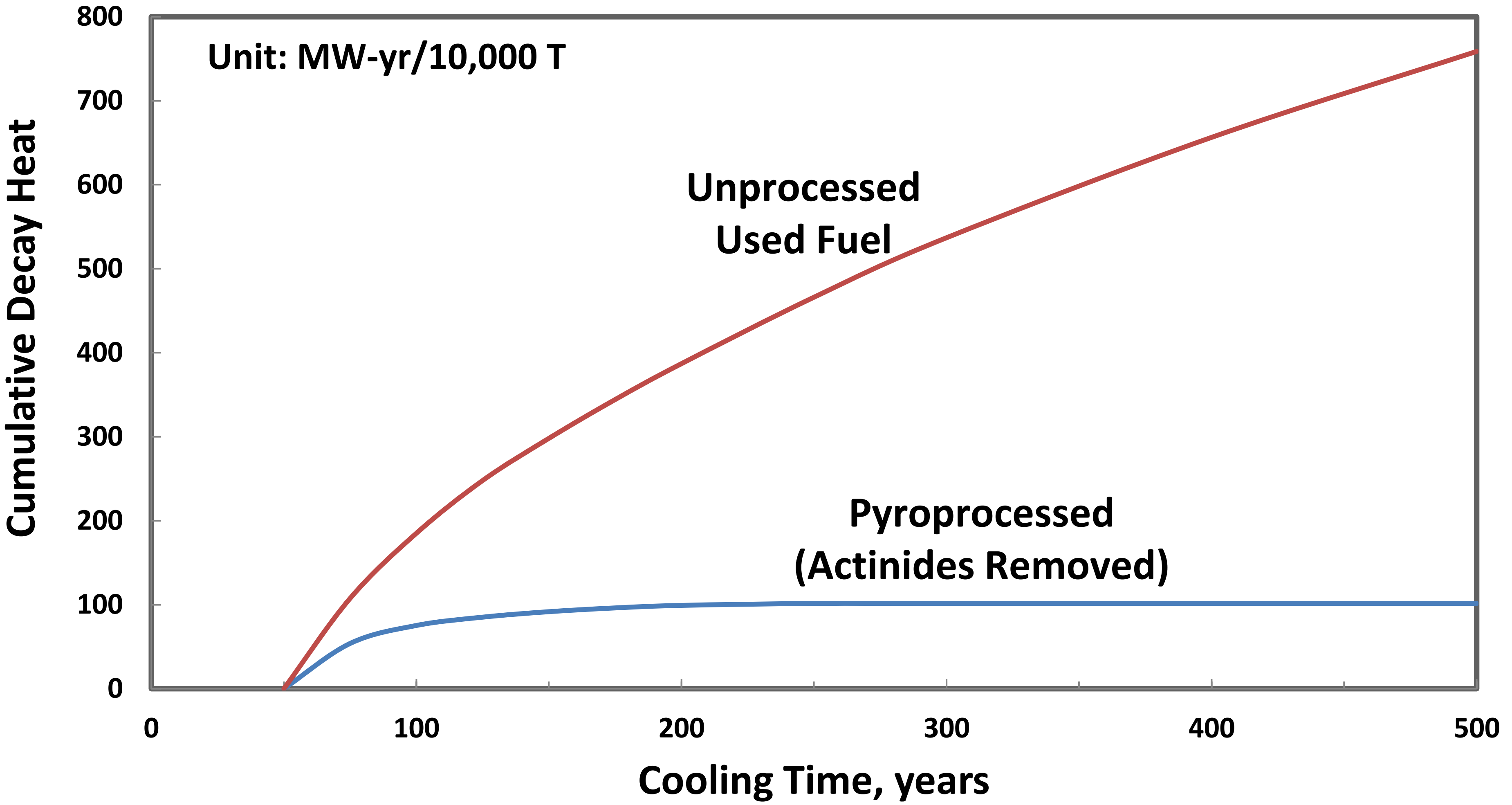
- Assumes intact titanium drip shield for 20,000 years.
- Assumes intact Alloy-22 engineered barrier for 20,000 years, 0.001 annual failure rate after that, and 0.5 in 100,000 years.



# IMPLICATIONS OF PYRO/SFR ON SPENT FUEL MANAGEMENT

- If the LWR used fuel is pyroprocessed and the recovered actinides are burned in SFRs, the long-term radiological toxicity is reduced by a factor of 1,000 and the effective lifetime of nuclear waste is reduced from 300,000 years to 300 years.
- The actinides recovered by pyroprocessing can be effectively burned only in fast reactors.
- This is by far the most effective and advanced technology, which provides a definitive solution to used fuel management:
  - Repository is still needed but the siting will be easier.
  - Repository requirements can be met on *a priori* basis without the source term.
- It is our responsibility to free our future generations from the burden of radioactive nuclear waste legacy.

# ACTINIDE REMOVAL ALLOWS 5-10 TIMES IMPROVEMENT IN REPOSITORY SPACE UTILIZATION



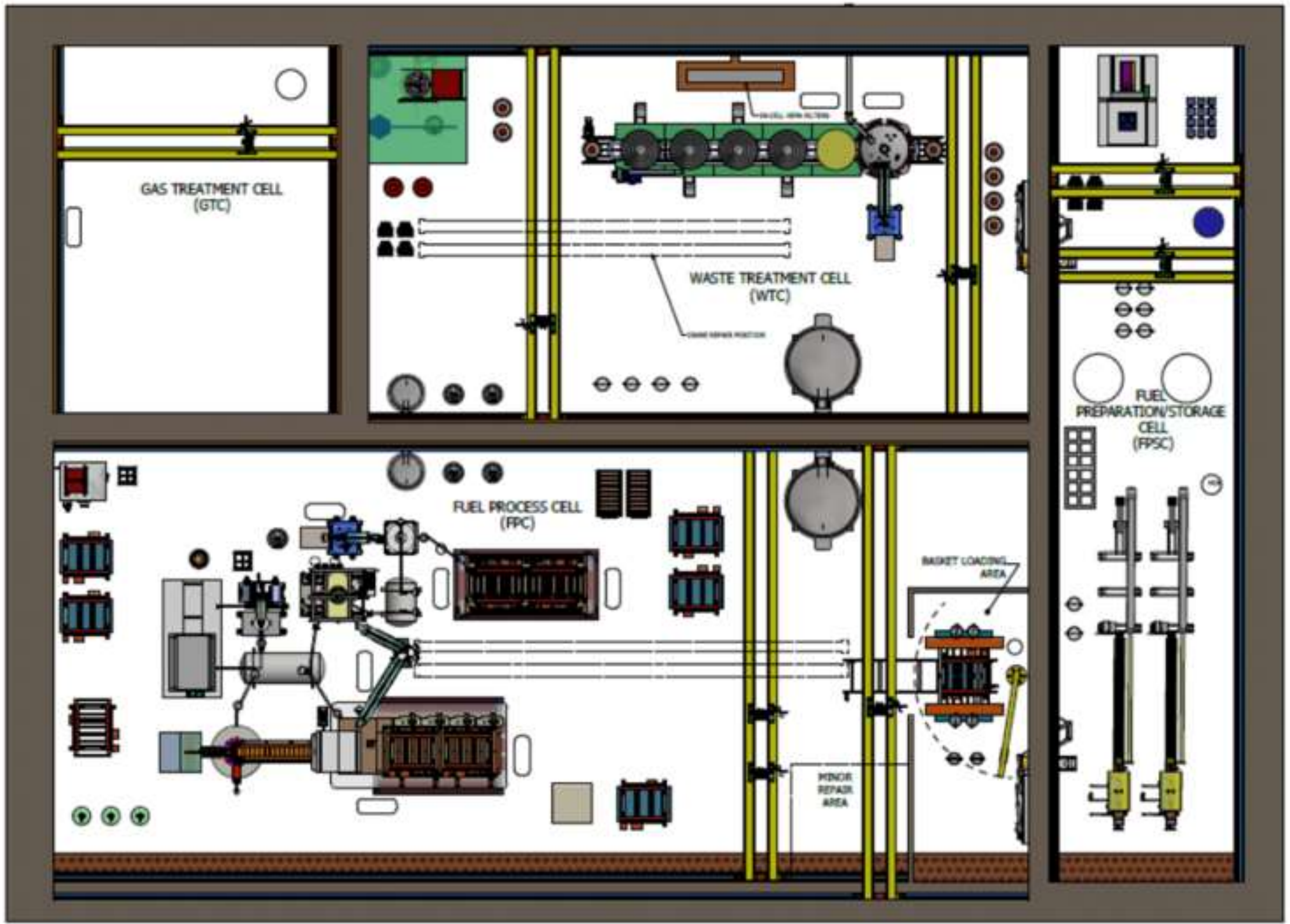
# PYROPROCESSING FOR LWR SPENT FUEL

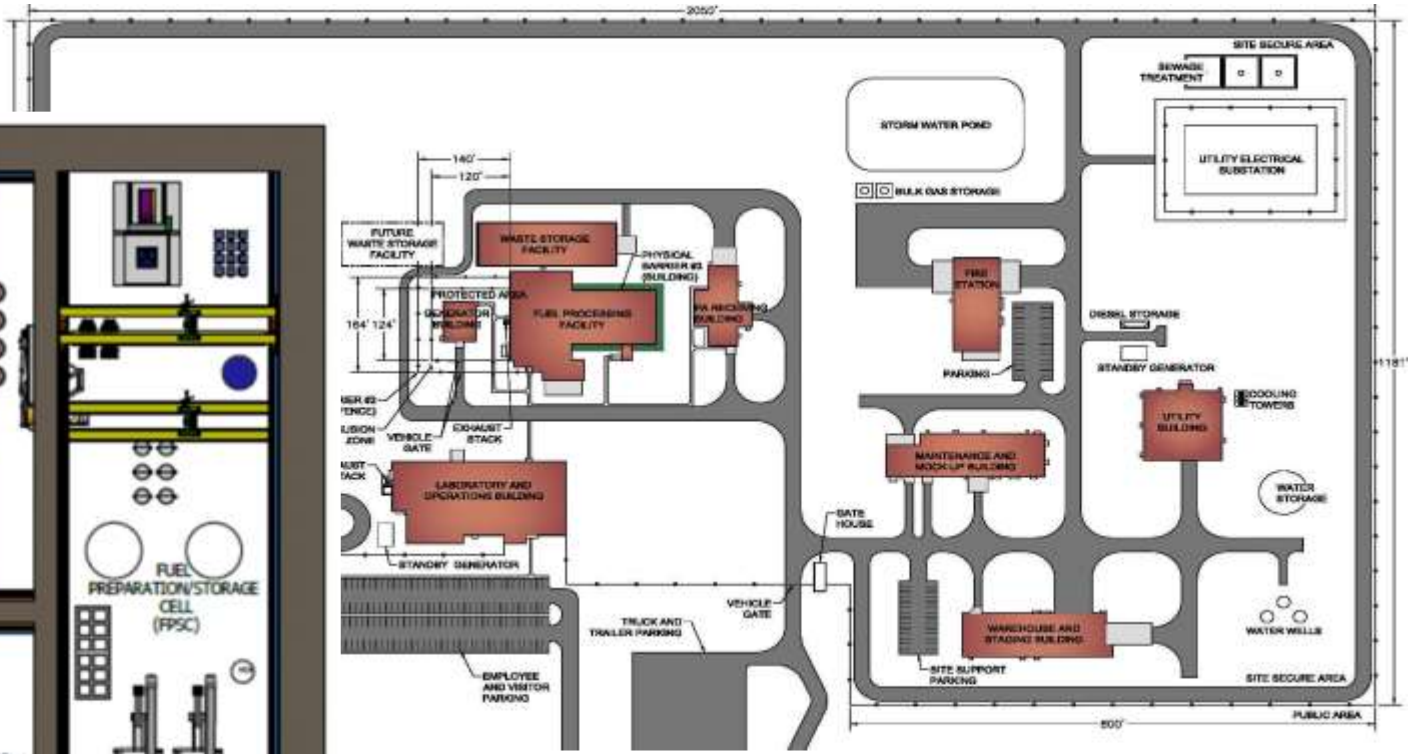
- pyroprocessing has been demonstrated for fast reactor metal spent fuels.
- For LWR spent fuel application, oxide-to-metal reduction front-end step is required:
  - Electrolytic reduction process
- For economic viability, the electrorefining batch size and throughput rate has to be increased: this should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

# LANDMARK CRADA PROJECT FOR PILOT-SCALE PYROPROCESSING FACILITY

- Cooperative Research and Development Agreement (CRADA) sponsored by the Landmark Foundation
- Development of a conceptual design of a pilot-scale (100 T/yr) pyroprocessing facility for LWR used fuel
  - Detailed engineering to allow credible capital and operating cost estimates
- Progress to date:
  - Phase I (03/2013 – 05/2015): Conceptual Design completed
  - Phase II (01/2016 – present): Safety, security, and safeguards assessments, design updates, 400 T/yr facility assessment
  - Phase III (under negotiation): NRC licensibility assessment

# PILOT-SCALE PYROPROCESSING FACILITY
# COMPACT HOT CELL WITH ONLY FEW PROCESS EQUIPMENT




52 acre site

Hot cell size: 85’ x 120’ x 40’H

# CAPITAL AND OPERATING COSTS

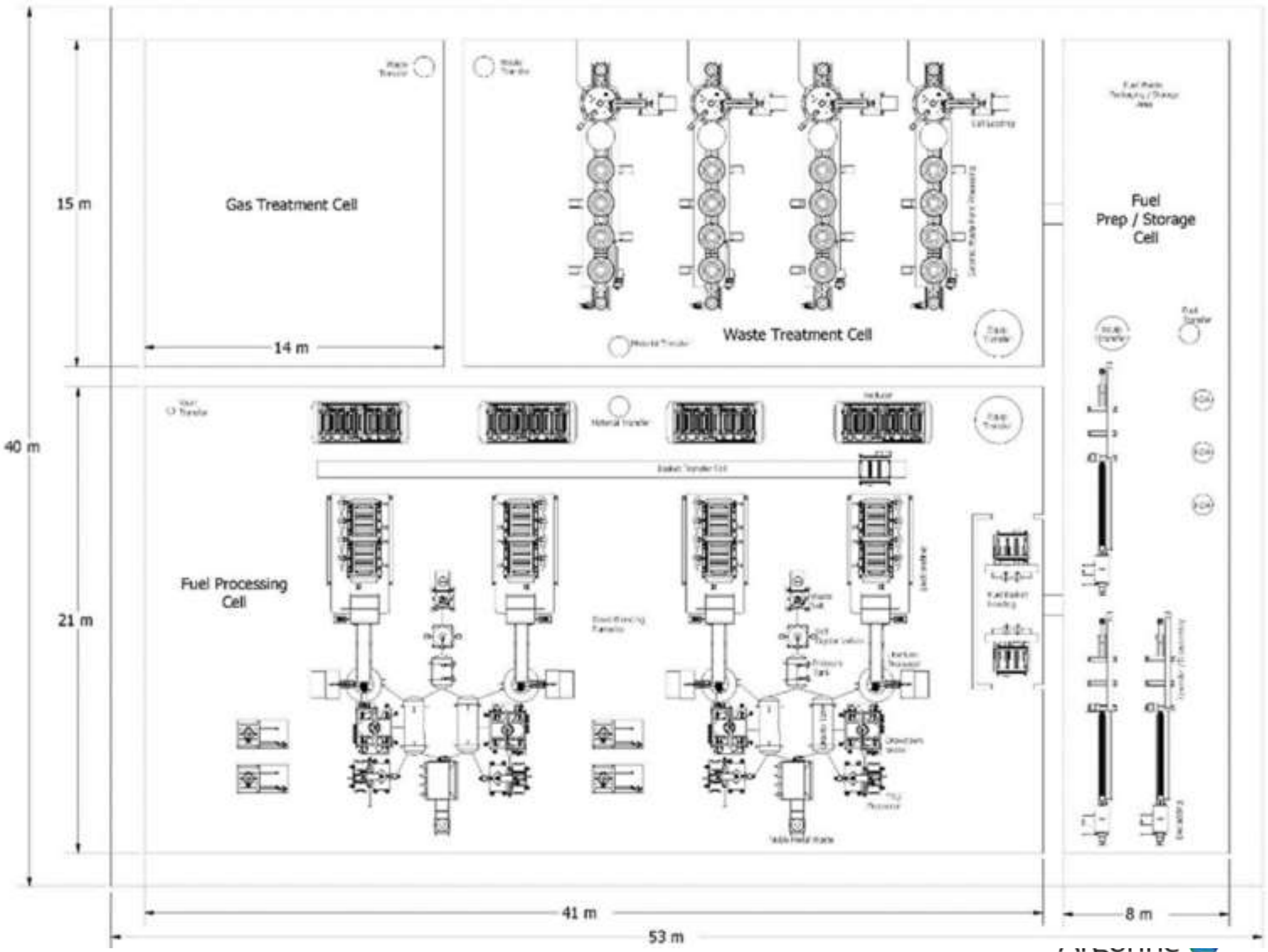
- Capital Cost ($ million in 2026 dollars)

| Category | Cost w/o C. F. | Contingency Factor, % | Cost with C. F. |
|---|---|---|---|
| Facility | 353 | 15-25 | 415 |
| Equipment | 108 | 10-25 | 138 |
| Total | 461 | | 553 |

- Operating Cost: $74 million /year

# POTENTIAL FOR SCALING UP TO COMMERCIAL-SCALE (400 T/YR)

- Significant economies of scale are achieved for 400 T/yr facility.
- Hot cell area is increased by a factor of 1.8 even if the same size equipment is duplicated.
- Capital cost of $1,265 million and operating cost of $125 million per year for a 400 T/yr facility.
- Similarly, it was also estimated that a 2000 T/yr commercial-scale facility would cost $3.3 billion capital and $289 million per year operating cost.



# ECONOMIC IMPACT ON REPOSITORY

- Assuming a fixed charge rate of 5%, the commercial-scale processing cost will be $190/kgHM.
- Assuming 50,000 MWD/T burnup, the above pyroprocesssing cost translates to 0.48 mill/kWhr.
- At a fraction of 1 mill/kWhr, we can render the used fuel almost harmless. It will cost less to dispose benign waste form in a geological repository. Hence, it is plausible both pyroprocessing and permanent disposal can be realized within the current waste fee.
- At the same time, valuable resources are recovered to make nuclear sustainable for thousands of years.

# PROPOSED NEXT STEP

- Pyroprocessing of LWR spent fuel allows:
  1. Effective lifetime of nuclear waste is reduced from ~300,000 years to ~300 years, making the repository siting and regulatory compliance much easier.
  2. Potentially economic enough to do both pyroprocessing and repository within the current waste disposal fund.
  3. The byproduct actinides are valuable resources to assure sustainability of nuclear in the long-term.
- Hence, a pilot-scale pyroprocessing demonstration project should be given an immediate priority with a goal of validating licensability and economic viability.