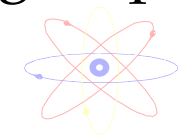
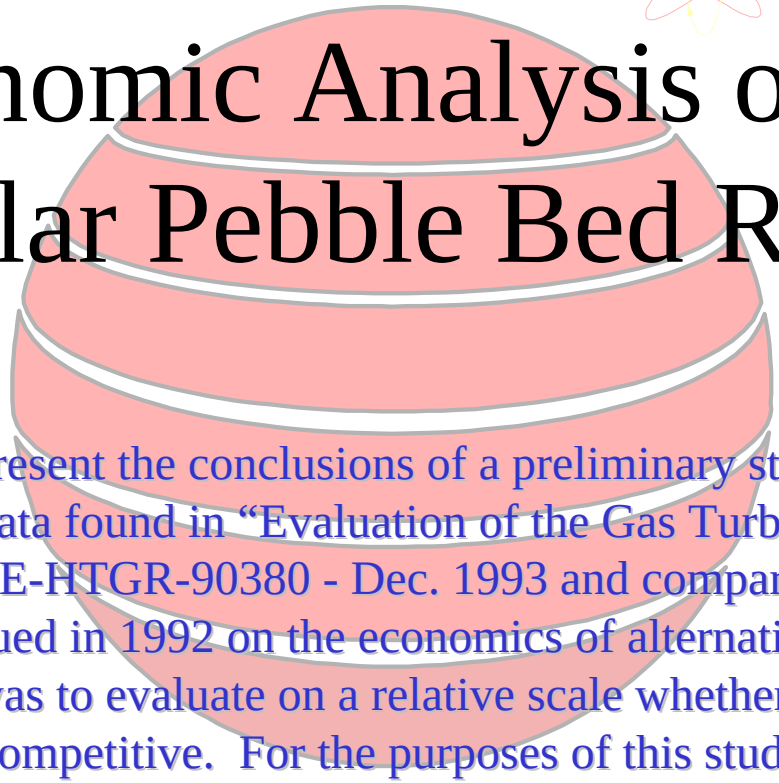
Pebble Bed Reactor Project

MIT Nuclear Engineering Department



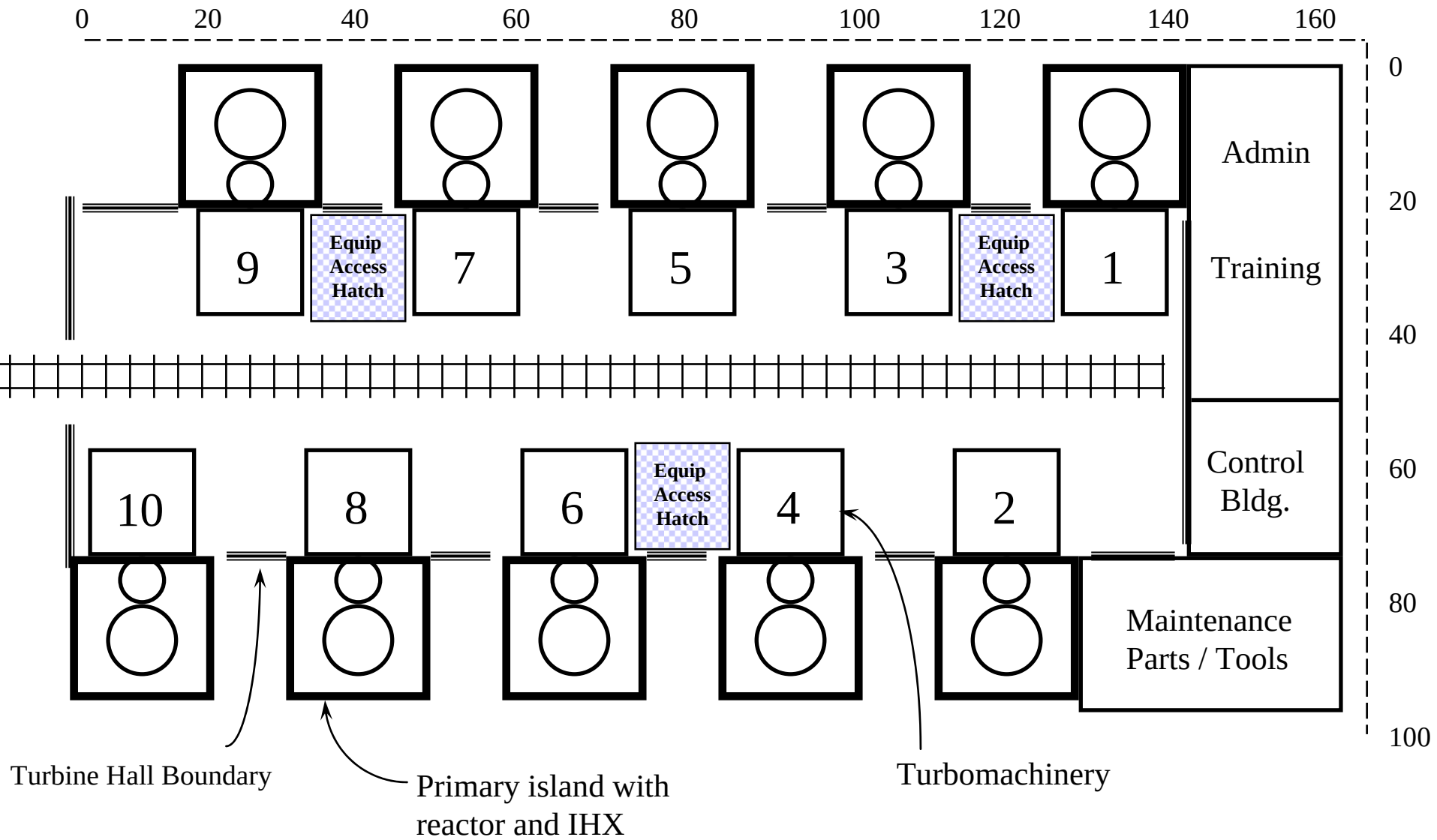
Economic Analysis of the Modular Pebble Bed Reactor



These slides present the conclusions of a preliminary study based on existing cost data found in "Evaluation of the Gas Turbine Helium Reactor" - DOE-HTGR-90380 - Dec. 1993 and compared against an NEI report issued in 1992 on the economics of alternative options. The purpose was to evaluate on a relative scale whether the pebble bed could be competitive. For the purposes of this study the gas price in 1992 was assumed constant and did not increase. This study will be revised as better data is developed.

June 1998

Ten-Unit MPBR Plant Layout (Top View)



Economic Analysis

- Group Goals
  - determine cost estimate for construction
  - compare cost estimate with that of existing technologies
  - examine financing options
  - examine economies of scale vs. productivity

MPBR Cost Estimate

- Capital cost
- O&M cost
- Fuel cost
- Decommissioning cost

Capital Cost

- Cost savings come from:
  - more factory fabrication, less site work
  - learning effect from 1st to 10th unit
  - natural safety features
  - shorter construction time
- Total capital cost for 1100 MWe plant

  $2,296 million

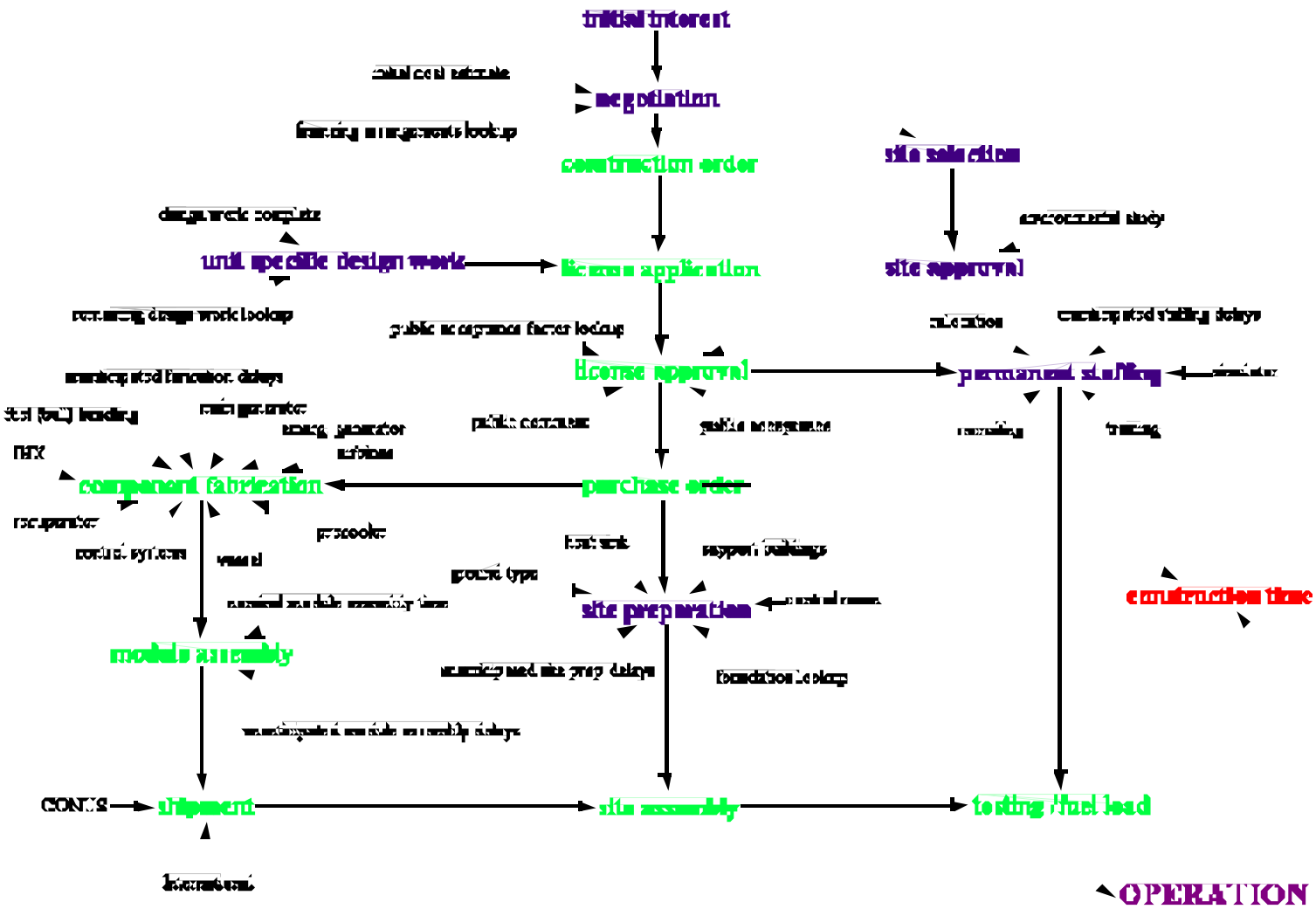
Plant Construction

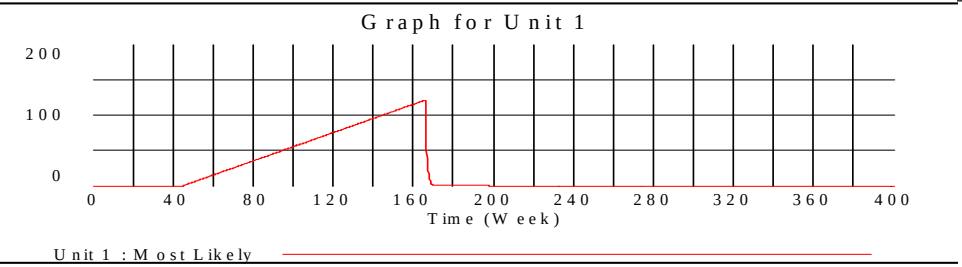
- Construction Plan / Techniques
- Plant Physical layout
- Construction Model

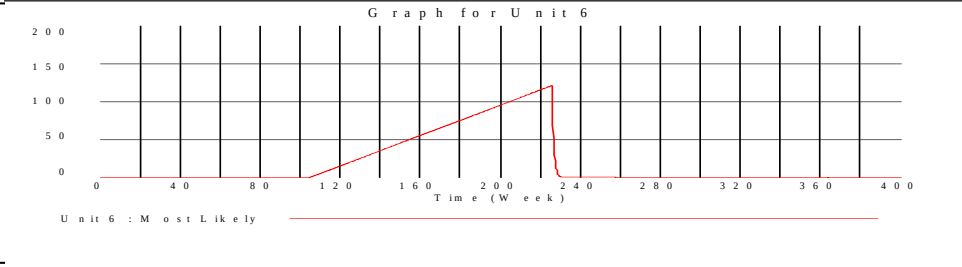
Construction Plan / Techniques

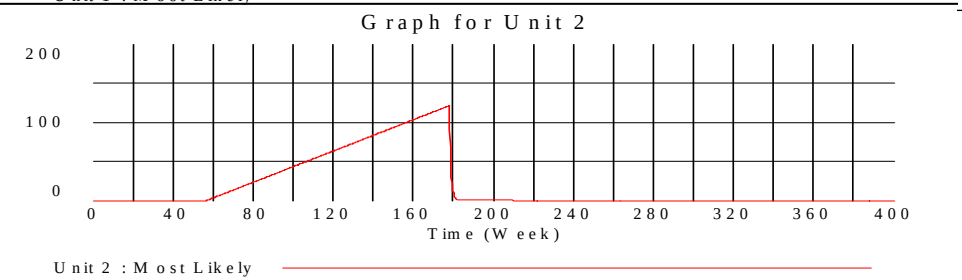
- Factory Assembly
- Existing Technology
- Modular Construction Allows:
  - Parallel Construction
  - Ease of Shipment
  - Rapid Assembly
  - Streamlined Testing

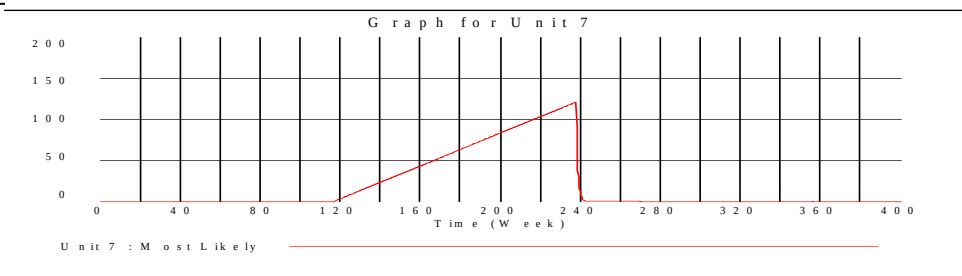
Construction Flowpath for a Standard Unit

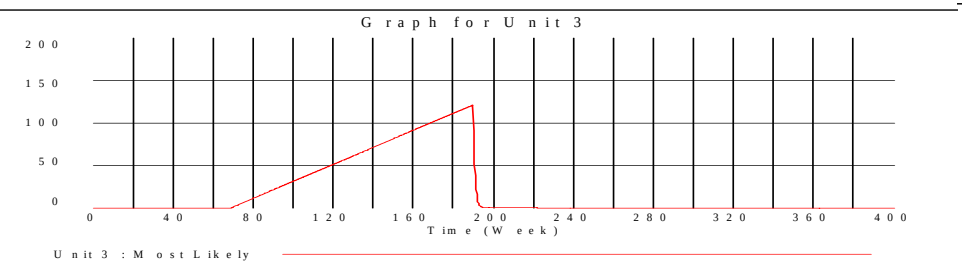


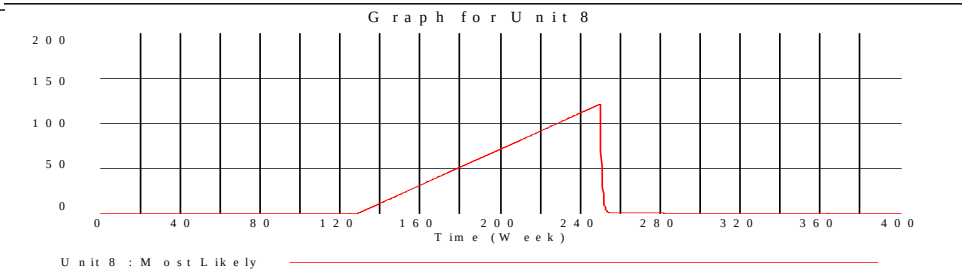

Graph for Unit 1
200
100
0
0 40 80 120 160 200 240 280 320 360 400
Time (Week)
Unit 1 : Most Likely

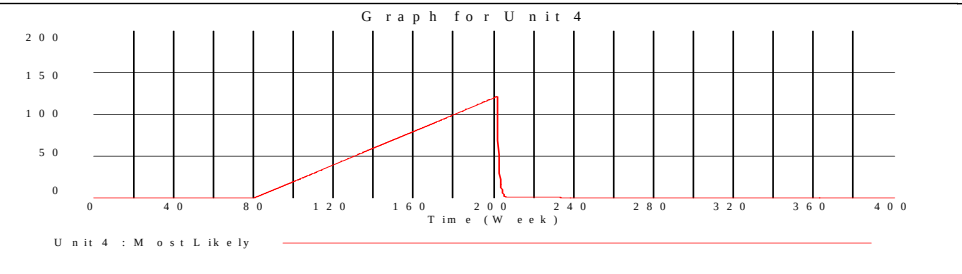

Graph for Unit 6
200
150
100
50
0
0 40 80 120 160 200 240 280 320 360 400
Time (Week)
Unit 6 : Most Likely

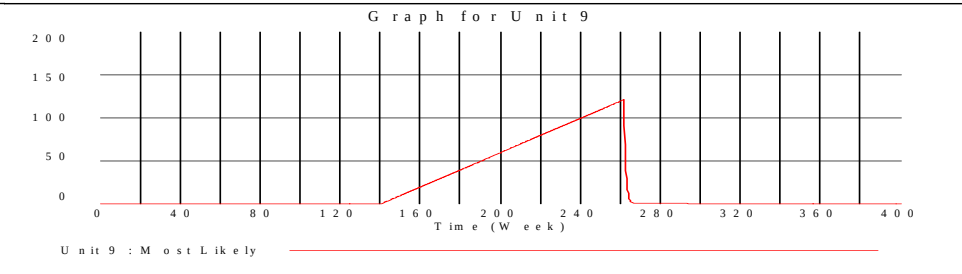

Graph for Unit 2
200
100
0
0 40 80 120 160 200 240 280 320 360 400
Time (Week)
Unit 2 : Most Likely

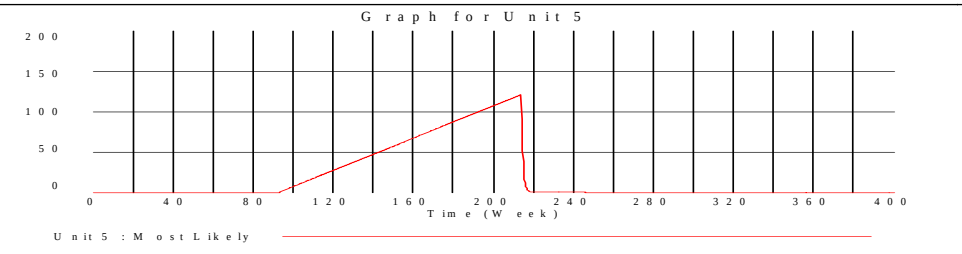

Graph for Unit 7
200
150
100
50
0
0 40 80 120 160 200 240 280 320 360 400
Time (Week)
Unit 7 : Most Likely

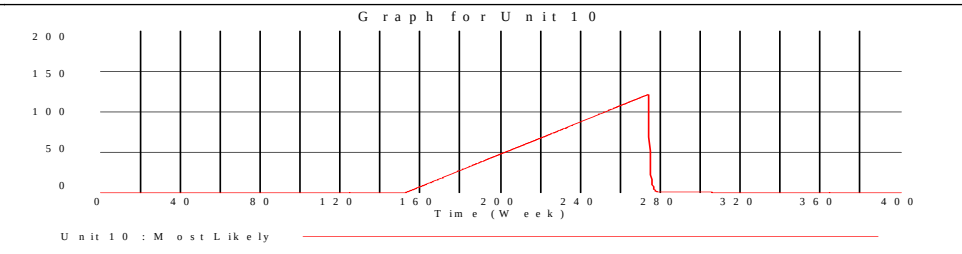

Graph for Unit 3
200
150
100
50
0
0 40 80 120 160 200 240 280 320 360 400
Time (Week)
Unit 3 : Most Likely


Graph for Unit 8
200
150
100
50
0
0 40 80 120 160 200 240 280 320 360 400
Time (Week)
Unit 8 : Most Likely

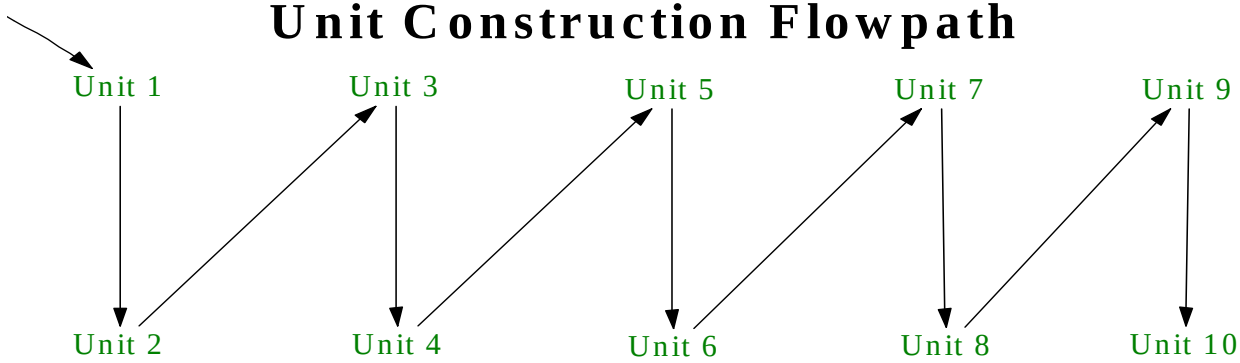

Graph for Unit 4
200
150
100
50
0
0 40 80 120 160 200 240 280 320 360 400
Time (Week)
Unit 4 : Most Likely


Graph for Unit 9
200
150
100
50
0
0 40 80 120 160 200 240 280 320 360 400
Time (Week)
Unit 9 : Most Likely

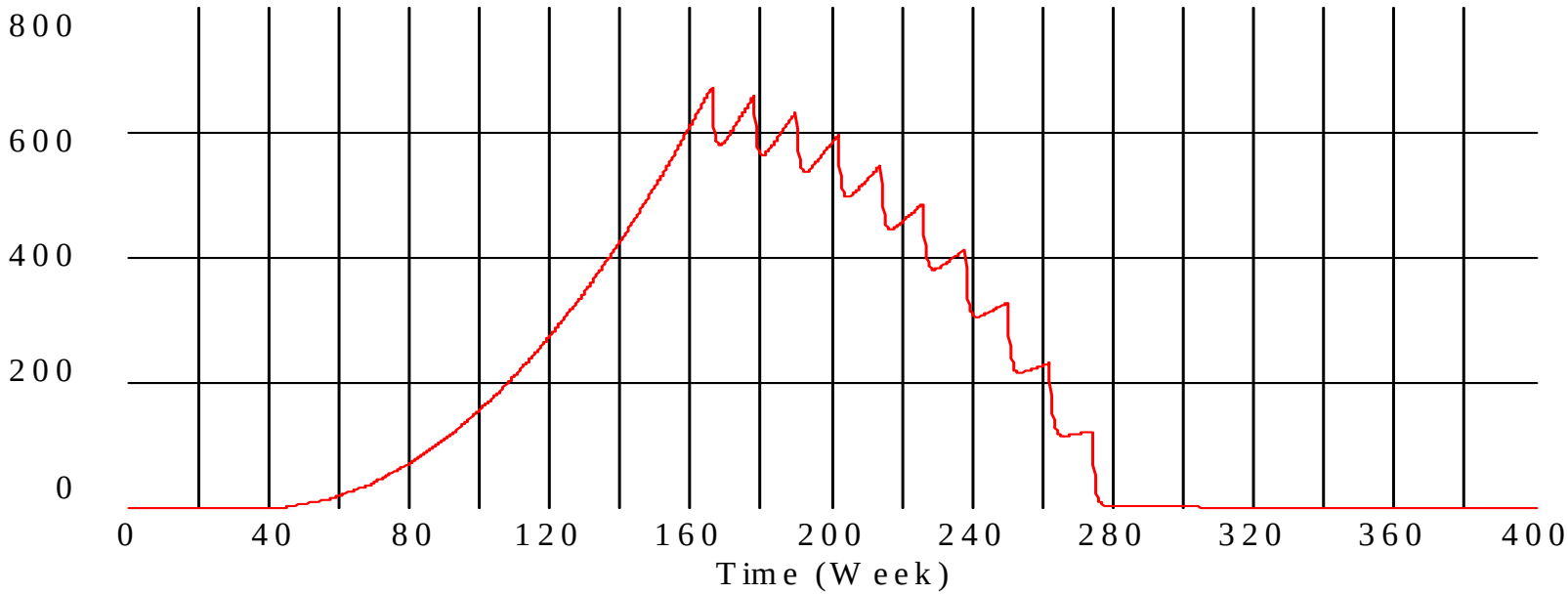

Graph for Unit 5
200
150
100
50
0
0 40 80 120 160 200 240 280 320 360 400
Time (Week)
Unit 5 : Most Likely

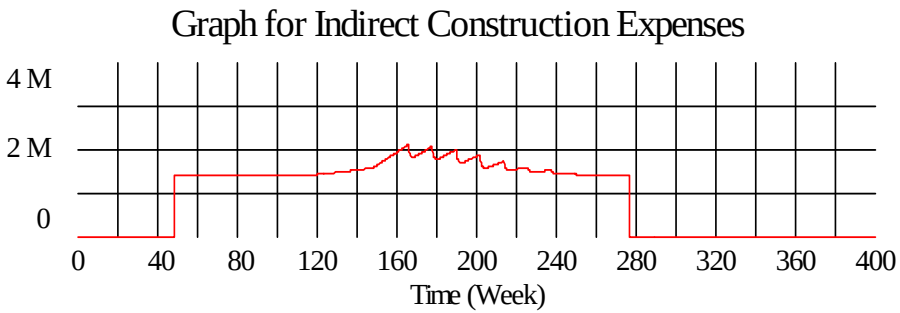

Graph for Unit 10
200
150
100
50
0
0 40 80 120 160 200 240 280 320 360 400
Time (Week)
Unit 10 : Most Likely

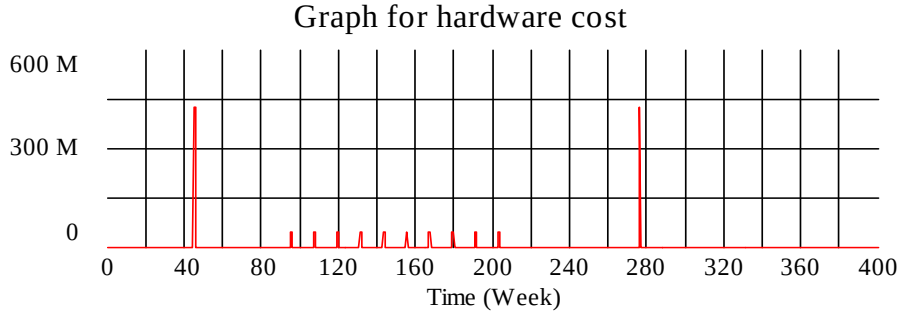
Unit Construction Flowpath

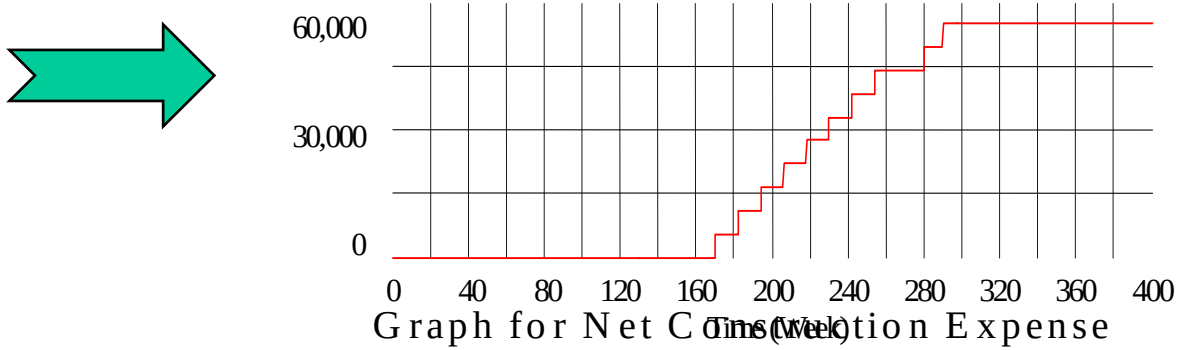


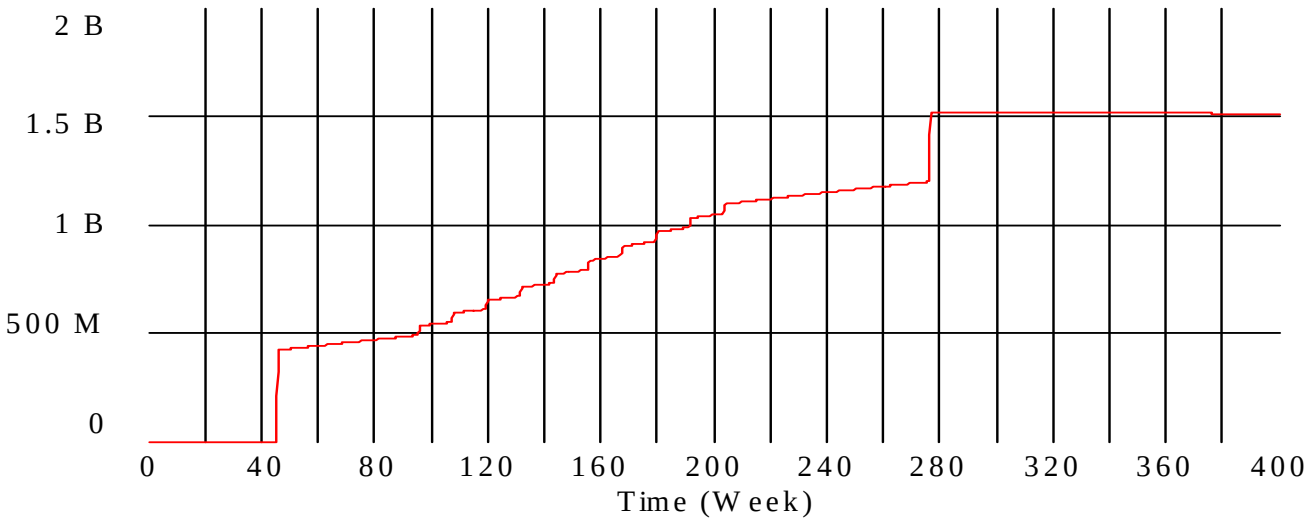
Graph for Instantaneous Work in Progress




Graph for Indirect Construction Expenses
4 M
2 M
0
0
40
80
120
160
200
240
280
320
360
400
Time (Week)
Indirect Construction Expenses : Most Likely
Dollars/Week


Graph for hardware cost
600 M
300 M
0
0
40
80
120
160
200
240
280
320
360
400
Time (Week)
hardware cost : Most Likely

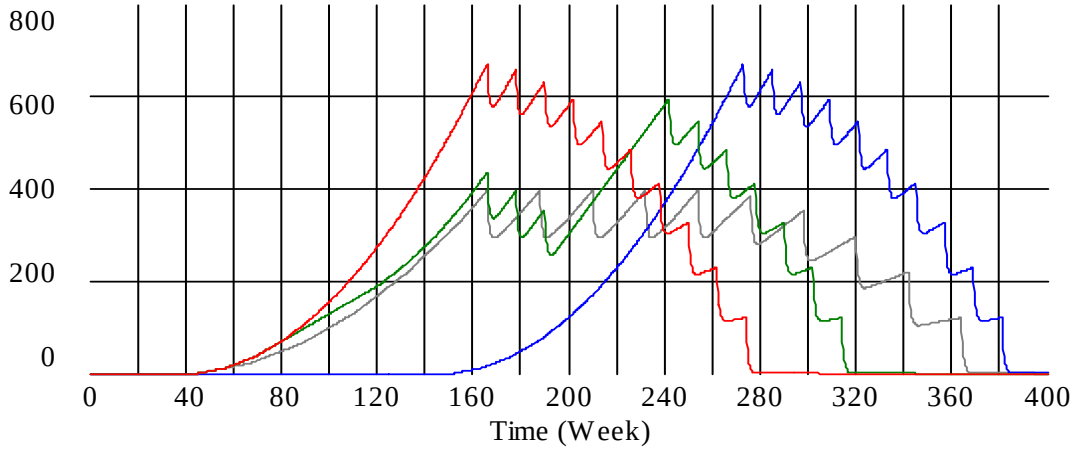

Graph for Income During Construction
60,000
30,000
0
0
40
80
120
160
200
240
280
320
360
400
Time (Week)


Graph for Net Construction Expense
2 B
1.5 B
1 B
500 M
0
0
40
80
120
160
200
240
280
320
360
400
Time (Week)
Net Construction Expense : Most Likely

Construction Model

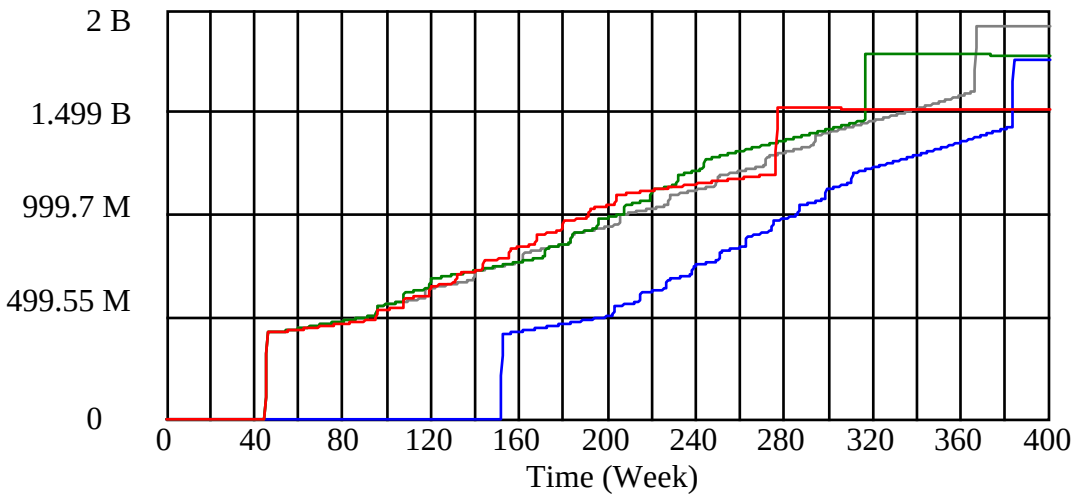
- Can it be done?
- Influence of external factors?
- What are vulnerabilities / areas for time and cost savings?
- What is the relationship between construction time and cash flow?
- Sensitivity analysis

Graph for Instantaneous Work in Progress



Instantaneous Work in Progress : Most Likely — Week
Instantaneous Work in Progress : Unit-4 Hits Water — Week
Instantaneous Work in Progress : Intervenors — Week
Instantaneous Work in Progress : Module Delay — Week

Graph for Net Construction Expense



Net Construction Expense : Most Likely
Net Construction Expense : Unit-4 Hits Water
Net Construction Expense : Intervenors
Net Construction Expense : Module Delay

MPBR PLANT CAPITAL COST ESTIMATE
(MILLIONS OF JAN. 1992 DOLLAR WITHOUT CONTINGENCY)

Account No.	Account Description	Cost Estimate
20	LAND & LAND RIGHTS	2.5
21	STRUCTURES & IMPROVEMENTS	192
22	REACTOR PLANT EQUIPMENT	628
23	TURBINE PLANT EQUIPMENT	316
24	ELECTRIC PLANT EQUIPMENT	64
25	MISCELLANEOUS PLANT EQUIPMENT	48
26	HEAT REJECT. SYSTEM	25
	TOTAL DIRECT COSTS	1,275
91	CONSTRUCTION SERVICE	111
92	HOME OFFICE ENGR. & SERVICE	63
93	FIELD OFFICE SUPV. & SERVICE	54
94	OWNERÕS COST	147
	TOTAL INDIRECT COST	375
	TOTAL BASE CONSTRUCTION COST	1,650
	CONTINGENCY (M$)	396
	TOTAL OVERNIGHT COST	2,046
	UNIT CAPITAL COST ($/KWe)	1,860
	AFUDC (M$)	250
	TOTAL CAPITAL COST	**2296**

O&M Cost

- Simpler design and more compact
- Least number of systems and components
- Small staff size: 150 personnel
- $31.5 million per year

Fuel Cost

- Assumptions:
  - One fuel pebble will cost $20.00 (‘92$)
  - One third of the fuel pebble bed is replaced annually (120,000 per unit per year)
  - 1.0 mill/kWh for spent fuel disposal and radioactive waste management
- Cost: $32.7 million / year

Decommissioning Cost

- $211 million
- Remove all radioactive wastes from site and all construction material to a level of 3ft below grade.
- Less than 1 mill/kWh levelized busbar cost

MPBR Busbar Generation Costs (‘92$)

Reactor Thermal Power (MWt)	**10 x 250**
Net Efficiency (%)	**45.3%**
Net Electrical Rating (Mwe)	**1100**
Capacity Factor (%)	**90**
Total Overnight Cost (M$)	**2,046**
Levelized Capital Cost ($/kWe)	**1,860**
Total Capital Cost (M$)	**2,296**
Fixed Charge Rate (%)	**9.47**
30 Year Level Cost (M$/yr):	
Levelized Capital Cost	**217**
Annual O&M Cost	**31.5**
Level Fuel Cycle Cost	**32.7**
Level Decommissioning Cost	**5.4**
Revenue Requirement	**286.6**
Busbar Cost (mill/kWhr):	
Capital	**25.0**
O&M	**3.6**
Fuel	**3.8**
Decommissioning	**0.6**
Total	**33.0**

Financing Construction

- Cost of capital
  - debt-to-equity ratio
  - distribution of risk
- Consortium approach
  - share risk
  - lower return on investment

Amortization of debt

- Determine annual revenue requirements
  - debt-to-equity ratio
  - return on preferred equity
  - return on common equity
  - income taxes

Debt Service Coverage

- Ratio of total revenue generated to annual revenue required
  - depends on amortization length
  - distribution of risk
- Consortium approach best

Competitive With Gas ?

- Natural Gas 3.4 Cents/kwhr
- AP 600 3.62 Cents/kwhr
- ALWR 3.8 Cents/kwhr
- MPBR 3.3 Cents/kwhr

Levelized Costs (1992 $ Based on NEI Study)

Group Findings

- Low levelized cost
  - low fuel cost
  - low O&M cost
- High unit capital cost
  - low capacity design
  - high contingency factor (24%)

Future Work

- Determine optimal capital structure
- Adjust cost estimate to design changes
- Create detailed cash flow statement

Major MPBR Conclusions

- Naturally Safe (Regulatory / Safety Implications)
  - Constrained by Fuel Particle failure above 1600^{o}C
    - Core power density chosen as 3.54 MW/m^{3}
    - Fuel pebble manufacturing defects are the most significant source of fission product release
- Economically Competitive
  - 3.3 cents/kWhr (natural gas = 3.4 cents/kWhr)
    - Producing revenue within 3 years (rapid construction)
    - Low staffing and O&M costs
    - Factory Assembly
- Societal Acceptance
  - Proliferation Resistance -- promising, but future work needed
  - Waste Disposal -- promising, but future work needed